FOSTERING A SPATIALLY LITERATE GENERATION: EXPLICIT INSTRUCTION IN SPATIAL THINKING FOR PRESERVICE TEACHERS

A Dissertation

by

INJEONG JO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2011

Major Subject: Geography

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Approved by:

Chair of Committee,	Sarah W. Bednarz
Committee Members,	Robert S. Bednarz
	Reuben R. Rose-Redwood
	Lynn M. Burlbaw
Head of Department,	Vatche P. Tchakerian

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ABSTRACT

Fostering a Spatially Literate Generation: Explicit Instruction in Spatial Thinking for Preservice Teachers. (December 2011)

Injeong Jo, B.A., Seoul National University; M.S., Texas A&M University

Chair of Advisory Committee: Dr. Sarah W. Bednarz

This research proposes that the explicit incorporation of spatial thinking into teacher preparation programs is an effective and efficient way to foster and develop a spatially literate populace. The major objective of this study was to examine the effect of explicit instruction in spatial thinking on the development of preservice teachers' knowledge, skills, and dispositions toward teaching it.

A one-day workshop – Teaching Spatial Thinking with Geography – for preservice geography teachers was developed as the intervention of this study. The primary focus of the workshop was to provide an explicit opportunity to learn about spatial thinking and to practice skills required to incorporate spatial thinking into participants' classrooms. Three assessments were used to examine changes in participants' knowledge, skills, and dispositions, before and after the workshop: the spatial concepts test, the teaching spatial thinking disposition survey, and participant-produced lesson plans. Individual interviews were conducted to obtain a deeper understanding of participants' learning experiences during the workshop. A mixed-method research design was adopted in which both quantitative and qualitative methods

were used to offset the weaknesses inherent within one method with the strengths of the other.

The major findings of this study include: 1) explicit instruction about spatial concepts is necessary to the development of preservice teachers' knowledge required for teaching spatial thinking through geography; 2) the skills development required to teach spatial thinking should be approached as the development of pedagogical content knowledge; 3) dispositions toward teaching spatial thinking should be differentiated from dispositions toward teaching general thinking skills; 4) although explicit instruction about teaching spatial thinking contributed substantially to the preservice teachers' acquisition of knowledge and skills and the development of positive dispositions toward teaching spatial, each of these components develops at a different rate but affect each other; and 5) a promising approach to the development of preservice teachers' pedagogical content knowledge would be to offer geography education courses, not general geography or methods courses, in which the focus is explicitly on teaching geography with an emphasis on spatial thinking.

DEDICATION

To Jongdoo and Jeesoo

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There are no words to express my deep gratitude to my parents who guided me to be who I am today. To my sisters, Inkyoung, Youngjoo, and Minjeong, you all deserve special thanks for always being wonderful conversational partners.

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TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

Spatial thinking has been defined in many ways, but one of the most compelling and comprehensive definitions is presented in a recent publication by the National Research Council (2006), *Learning to Think Spatially*, where it is characterized as, "a collection of cognitive skills comprised of knowing concepts of space, using tools of representation, and reasoning processes" (National Research Council 2006, 12). It is a mode of thinking used in the sciences including geography, and proficiency in spatial thinking is associated with success in many other disciplines such as engineering, architecture, medicine, and mathematics (Hegarty 2010; Hespanha, Goodchild, and Janelle 2009; LeGates 2009; Liben 2006; Newcombe 2010; Shea, Lubinski, and Benbow 2001). The National Research Council study makes the case that spatial thinking skills are not innate but rather, can- and should-be taught. However, the need to develop students' spatial thinking is currently not widely understood (Newcombe 2010) and it is not yet a systematic and integral part of the formal education system (Bednarz 2004; Liben and Downs 2003; Mathewson 1999; National Research Council 2006; Tversky 2005).

This dissertation follows the style of *Journal of Geography*.

Considering that spatial thinking is a key to success in a variety of contexts in a person's life, it seems imperative to integrate spatial thinking into the education system, including the curriculum, instructional practices, and assessments. As a school subject, geography can be a valuable vehicle to teach spatial thinking not only because fostering a generation of spatially literate citizens is one of the main goals of geography instruction (Geography Education Standards Project 1994; National Research Council 2006), but because geography has traditionally emphasized spatial perspectives and analysis (Downs 1994; Golledge 2002; Hanson 2004; Solem, Cheung, and Schlemper 2008). Spatial analysis has long been one of geography's core traditions but the use of the term is novel and only beginning to be widely used (Jo, Bednarz, and Metoyer 2010). Explicit integration of spatial thinking into school geography should contribute to the development of a spatially-literate populace. The research on spatial thinking in geography education in the last decade indicates ongoing efforts to incorporate spatial thinking into geography classrooms. This research, however, has mostly focused on the curriculum, in a broad sense, including formal courses, students' classroom activities, and technologies implemented to support spatial thinking. Little effort has been made to incorporate spatial thinking into geography assessments (e.g., Texas Assessment of Knowledge and Skills) or teacher education programs which largely affect a teacher's knowledge and skills of instruction (Darling-Hammond 2006a; Doppen 2007; Golightly, Nieuwoudt, and Richter 2006).

This research proposes that the explicit incorporation of spatial thinking into teacher preparation programs is an effective and efficient way to foster and develop a spatially literate populace. Specifically, this research examines the effect of explicit instruction in spatial thinking on preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking. This study approaches the issue of the development of students' spatial thinking skills from the perspective of producing spatially informed teachers. The rationale for focusing on interventions for teachers is that the potential of any educational activity and material designed to promote students' learning relies more on how it is implemented than on its inherent structure and function (Adler 2008; Darling-Hammond 2006b; Gamoran and Nystrand 1992; Hill 1994). That is, the degree to which an educational activity or material contributes to student learning to think spatially will vary, depending on how many teachers are able to and willing to incorporate the activity or material into their classrooms with explicit aims to support students' spatial thinking. The rationale for focusing particularly on preservice teachers are twofold. First, preservice education is the time when prospective teachers are forming their perceptions about, as well as their knowledge of, the subject areas they will be teaching (Doppen 2007; Golightly, Nieuwoudt, and Richter 2006). Second, preservice experiences are often considered the key to success of the implementation of educational innovations (Bednarz and Audet 1999).

CONTEXT OF THE STUDY

Learning to Think Spatially

Expertise in a academic domain is a result of extensive exposure over time to the knowledge and ways of thinking in the domain (Feltovich, Prietula, and Ericsson 2006;

Hoffman and Lintern 2006). This may well be true for expertise in spatial thinking. Acquiring expertise in spatial thinking takes time and practice. It also requires: 1) acquisition of knowledge about a wide range of spatial concepts; 2) acquisition of skills to flexibly use, interact with, and create spatial representations; and 3) opportunities for guided practice in challenging but well-supported projects (Downs 1994; Ericsson 2006; Hegarty 2010; National Research Council 2006). Expertise in spatial thinking we know is domain-specific (Hegarty 2010; National Research Council 2006), and therefore the acquisition of knowledge and skills through guided practice should occur within the context of the specific domain, for example, geography.

Despite such consensus about the nature of spatial thinking and increasing recognition of the importance of spatial thinking (National Research Council 2006; Ramadas 2009; Solem, Cheung, and Schlemper 2008), few studies inform how to promote this important skill in schools. As the report by the National Research Council (2006), *Learning to Think Spatially*, pointed out, the question of what kinds of experiences contribute to students' learning to think spatially has not yet been precisely answered. Various disciplines, such as psychology, behavioral geography, and education psychology have studied spatial thinking, but the findings are too fragmented to inform a consistent principle to design educational interventions to enhance students' spatial literacy.

Recent research in the field of education provides some insights into the types of learning experiences that positively affect students' spatial thinking skills. Academic coursework in Geographic Information Systems (GIS) proves to enhance spatial thinking skills (Lee and Bednarz 2009; Weakley 2010). Using geospatial technologies including Virtual Globes such as Google Earth, remotely sensed imagery, and GIS as instructional tools seems to help students learn to think spatially (Bodzin 2011; Kerski 2008; Milson and Curtis 2009; Schultz, Kerski, and Patterson 2008). Teaching and learning with maps has long been emphasized as a way to develop spatial thinking skills (Davies and Uttal 2007; Tversky 2000; Uttal 2000). Other classroom activities recommended to facilitate spatial thinking include informal journal writing in world geography courses (Hooey and Bailey 2005), observing and classifying practice in science classes (Llewellyn 2009), and using blocks in mathematics courses (Taylor-Cox 2009). The focus of these studies is either on the characteristics of a lesson or on the technologies that can facilitate students' spatial thinking. Although not exclusive, the insights to be learned from these studies are associated more with the development of a curriculum and curricular support materials rather than with teacher practices or assessments.

Teaching Spatial Thinking through Geography

Spatial thinking lies at the center of geographic knowledge and ways of thinking (Bednarz 2006; Bednarz, Downs, and Vender 2003; Downs 1994; Geography Education Standards Project 1994; Gersmehl 2005; Golledge 2002; Liben 2006; National Research Council 2006). In that regard, learning to think geographically would contribute to the development of spatial thinking skills and, in actuality, would foster a generation of spatially literate students, one of the main goals of geography instruction (Geography Education Standards Project 1994; National Research Council 2006).

It is not expected, however, that all geography courses or all geography teachers would contribute to the promotion of students' spatial thinking to the same degree. The potential of any educational activity and material designed to promote students' learning relies more on how it is implemented than on its inherent structure and function (Adler 2008; Darling-Hammond 2006b; Gamoran and Nystrand 1992; Hill 1994). The importance of the teacher's knowledge and skills cannot be overemphasized, especially with the view of a teacher as a curricular-instructional gatekeeper (Thornton 1989).

Then, what kinds of knowledge and skills should teachers possess to be an effective teacher? Regarding this question, Shulman's (1986, 1987) theory of pedagogical content knowledge has been central to teacher education research for the last two decades. A teacher's pedagogical content knowledge is described as a "special amalgam of content and pedagogy that is uniquely the province of teachers" and "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman 1987, 8). It is the knowledge that distinguishes the understanding of the content specialist from that of the expert teacher. Numerous studies have acknowledged a teacher's pedagogical content knowledge as an important characteristic of an effective teacher (Brophy 1991; Carlsen 1999; Guyver and Nichol 2004; Phelps and Schilling 2004).

As for spatial thinking, specific knowledge of good instructional practices in geography that can foster students' spatial thinking skills is lacking; characteristics of teachers that can affect students' learning to think spatially is not yet understood; and little research has examined how teachers learn or develop their knowledge, skills, and dispositions toward teaching spatial thinking and what kinds of learning experiences facilitate teachers' learning to teach spatial thinking.

Preparing Teachers to Teach Spatial Thinking

Little doubt exists that teachers' knowledge and skills grow with classroom experience. Mohan (2009) stressed that it is critical for researchers to view teachers as "life-long learners, always constructing new knowledge and skills, rather than ending their own education when they enter the door of their first classroom" (Mohan 2009, 26). However, it is also true that teachers generally teach as they have been taught (Adler 2008; Bednarz and Audet 1999; Darling-Hammond 2006b; Petry 1995). It is especially the case for beginning teachers. The particular importance of teacher preparation programs comes into play here because it is the time when prospective teachers are forming their perceptions about, as well as their knowledge of, the subject areas they will be teaching (Darling-Hammond 2006a, 2006b; Doering et al. 1995; Doppen 2007). Especially when implementing new ideas and materials in education, for example, National Geography Standards, GIS, and spatial thinking in geography education, preservice training is considered the key to success (Bednarz and Audet 1999; Boehm, Brierley, and Sharma 1994; Phillips 1994). Thus, it seems obvious that geography preservice teacher education should address spatial thinking and prepare preservice teachers to be able to teach spatial thinking in their future classrooms.

While the body of research on spatial thinking in geography education has been expanding and there are growing interests in introducing spatial thinking into geography classrooms, less research has focused on the preparation of geography teachers to be able to incorporate spatial thinking into their classrooms. Most research on preservice geography teachers to date has examined the level of their subject knowledge, particularly of place names and locations (e.g., Herman and Hawkins 1985; May 2005; Wiegand and Stiell 1997), and their self efficacy of teaching specific areas of geography, for example, physical geography, human geography, and GIS (e.g., Rynne and Lambert 1997). Studies have often reported preservice teachers' lack of geographic knowledge and skills and inadequate preparation for teaching geographic concepts and thinking in a very general sense. What is missing is whether the curriculum and instructional strategies for preparing geography teachers address knowledge and skills required to teach spatial thinking. No study has examined the kinds of learning experiences and educational strategies that lead preservice teachers to learn what spatial thinking is and how it can and should be taught.

Theoretical Framework of the Study

Figure 1 presents the theoretical framework of this study. As mentioned, this study is concerned with preparing teachers to be able to teach spatial thinking, expecting their enhanced knowledge, skills, and dispositions toward spatial thinking are transformed into instructional practices that eventually contribute to the development of student spatial thinking skills.

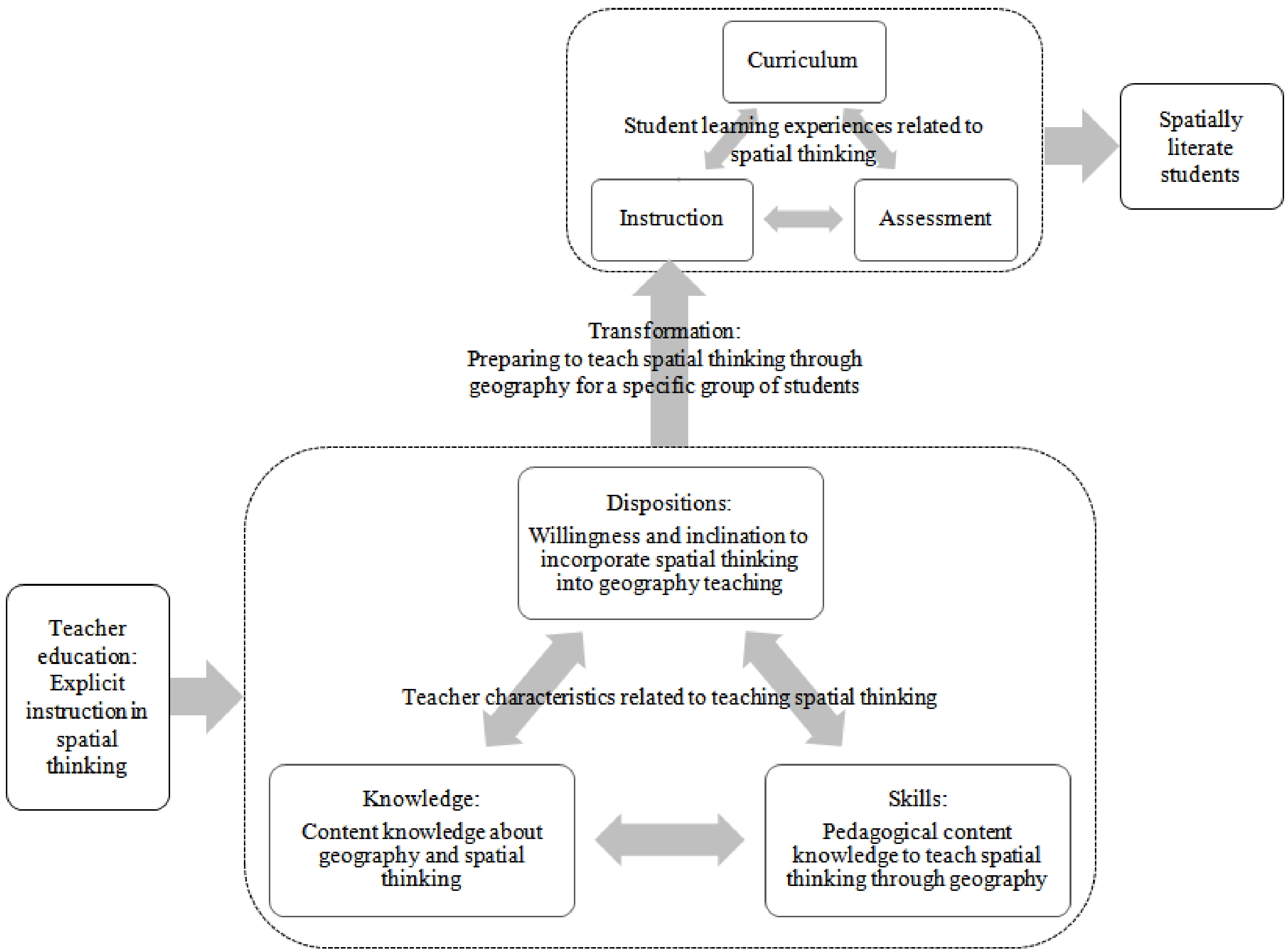


Figure 1. Theoretical framework of enhancing students' spatial literacy through explicit instruction in spatial thinking in teacher education.

A report by the National Research Council (2001), *How People Learn*, provided a basis for the first part of the framework. The report states that one of the most important goals of education is to improve students' "abilities to become active learners who seek to understand complex subject matter and are better prepared to transfer what they have learned to new problems and settings" (National Research Council 2001, 13). To achieve this goal depends largely on what is taught, how it is taught, and how learning is assessed (National Research Council 2001). This premise was represented in the framework where the outcome of student learning is viewed as a result of complex interactions among curriculum (what is taught), instruction (how it is taught), and assessment (how learning is assessed). Contextualizing this into student learning of spatial thinking, it can be reasoned that to achieve the goal of promoting students' spatial thinking skills, spatial thinking requires explicit attention in the curriculum, the teacher's instructional practices, and in assessments.

The second part of the framework represents the focus of this study, enhancing preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking through explicit instruction in spatial thinking in teacher preparation programs. This is based on theories that specifically address teacher education and teacher effectiveness. Shulman's (1986, 1987) theory of pedagogical content knowledge is one of the most compelling theories as it emphasizes integration of the teacher's knowledge of the subject matter with the knowledge of pedagogical strategies to promote student learning. Shulman (1987) first identified a list of the knowledge and skills teachers need to teach subject matter effectively. This list includes: 1) content knowledge; 2) general pedagogical knowledge; 3) curriculum knowledge; 4) pedagogical content knowledge; 5) knowledge of learners and their characteristics; 6) knowledge of educational contexts; and 7) knowledge of educational ends, purposes, and values, and their philosophical and historical grounds.

Among these, content knowledge (denoted as 'knowledge' in the framework) and pedagogical content knowledge (denoted as 'skills' in the framework) were of particularly interest in this study as they are directly related to teaching spatial thinking in the context of the subject of geography. Content knowledge refers to "the amount and organization of knowledge per se in the mind of the teacher" (Shulman 1986, 9). It is content knowledge that enables teachers to "define concepts and accepted truths in a domain" (Shulman 1986, 9) and to "explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions" (Shulman 1986, 9). In the context of teaching spatial thinking with geography, a teacher's content knowledge can be conceptualized as knowledge about the subject matter of geography and knowledge about spatial thinking as a way of thinking used both within the discipline of geography and outside of it. Pedagogical content knowledge refers to "the subject matter knowledge for teaching," (Shulman 1986, 9) which is a "special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman 1987, 8). Thus, pedagogical content knowledge for teaching spatial thinking can be defined as the teachers' ability to represent geographic concepts and ideas in a way to promote students' spatial thinking skills.

Meanwhile, recent literature on teacher education points out that knowledge and skills are not sufficient by themselves to prepare teachers because having required knowledge and skills to teach something does not guarantee the inclination to do so (Dottin 2009). According to Schussler (2006), teacher dispositions are operating “as both a point of convergence, representing a filter through which a teacher frames his/her thinking and behaviors, and a point of inception, from which knowledge and behaviors emanate” (Schussler 2006, 259). In other words, the degree to which a teacher incorporates spatial thinking into their daily practices may vary, depending not only on the level of their knowledge and understandings of spatial thinking but on dispositions toward teaching it. In this study, the term disposition is used to express the underlying motivator and organizer of a teacher’s instructional behaviors (Ritchart 2002), which include beliefs, awareness, and inclinations. Under such conceptualizations, developing teacher dispositions can be viewed as a matter of enhancing teachers’ awareness of, inclinations toward, and reflections on what they teach and how they teach it. Teacher dispositions toward teaching spatial thinking, therefore, can be defined as a teacher’s awareness of spatial thinking as an important thinking skill, beliefs that spatial thinking can and should be taught, and inclinations to incorporate spatial thinking into a class in an explicit manner.

As illustrated in the framework, teachers’ knowledge, skills, and dispositions are not necessarily exclusive of each other. Rather, it seems that they are closely related and continuously affect each other. For example, the development of one’s pedagogical content knowledge may not be successful without content knowledge of the domain. A high level of disposition toward teaching specific topics may motivate a teacher to pursue further knowledge and skills related to teaching those topics. It is also possible that an enhanced knowledge and skill of teaching a subject may contribute to a more positive disposition toward teaching it. In this study, therefore, a teacher's ability to teach spatial thinking is viewed as a representation of the complex interactions among the teacher's knowledge, skills, and dispositions toward teaching spatial thinking. Instructional practices observed in a classroom would be a result of the transformation of this ability, taking the characteristics of the group of students that the teacher teaches into consideration.

OBJECTIVES AND RESEARCH QUESTIONS

Shulman's theory of pedagogical content knowledge has geared the reform of teacher preparation programs, in which the emphasis has become more on the preservice teacher's subject knowledge linked to the skills to represent it effectively in the classroom. The theory has also been tested, supported, and elaborated by numerous studies. Little has been done in the subject of geography (Mohan 2009), however, and there is no research focusing on pedagogical content knowledge to teach spatial thinking within the context of geography.

Theories of teacher disposition have shed light on understanding of a teacher's instructional practices as a form of knowledge and skills filtered through the teacher's dispositional characteristics. Research on the development of teacher dispositions has been expanding for the last decade, but no previous research exists on a teacher's dispositional characteristics that are specifically related to spatial thinking or even to geography. In addition, no research has explicated the relationship of teacher dispositions toward incorporating spatial thinking into teaching practices and the level of knowledge and skills required to teach spatial thinking.

This study seeks to address these gaps by examining the effect of explicit instruction in spatial thinking on preservice teachers' ability to teach spatial thinking. A one-day, approximately four hours long, workshop, focusing on explicit instruction about the idea of spatial thinking, its three components, and its applications in the classroom context, was designed and delivered to 24 preservice teachers. Participants' knowledge, skills, and dispositions toward teaching spatial thinking were measured before and after the workshop. The four operational research questions were:

1. Does explicit instruction in spatial thinking enhance preservice teachers' knowledge required to teach spatial thinking (content knowledge)?
2. Does explicit instruction in spatial thinking enhance preservice teachers' skills to teach spatial thinking (pedagogical content knowledge)?
3. Does explicit instruction in spatial thinking enhance preservice teachers' dispositions toward teaching spatial thinking in their future classrooms?
4. What is the relationship among preservice teachers' knowledge, skills, and dispositions related to teaching spatial thinking?

In answering these questions, this study also addresses two research needs. First, no previous research has measured the status of preservice teachers' knowledge, skills, and dispositions related to teaching spatial thinking skills. This study fills the gap by evaluating participants' knowledge about some of the important spatial concepts, skills to incorporate spatial thinking into a lesson, and beliefs and attitudes toward teaching spatial thinking in its pre-test phase. Secondly, little research has proposed how aspects of spatial thinking can be infused into the curriculum of teacher preparation programs both effectively and efficiently. This study provides some insights on this issue, based on an in-depth analysis of participant interviews about their learning experiences throughout the workshop.

STUDY SIGNIFICANCE

In terms of advancing basic knowledge, this study will provide insights into a fundamental question which has not yet been answered in geography, cognitive psychology, and education research: What is an effective way to promote preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking? This will be the first attempt to intervene with educators rather than learners to enhance spatial literacy in the general public. In addition, by focusing not only on teachers' knowledge and skills required to teach spatial thinking but on their dispositions toward teaching it, this study will fill a research gap since dispositional characteristics associated with teaching spatial thinking have not been examined in the spatial thinking literature.

In an applied sense, this study will provide not only an exemplary model unit which can directly be implemented into teacher preparation programs but valid tools to assess the learning outcomes. The result of this study will contribute as a first step to incorporating spatial thinking into current teacher preparation curricula. In addition, the instruments developed in the study, such as the spatial concepts test and teaching spatial thinking disposition survey, will offer teacher educators useful tools to diagnose and assess preservice teachers' knowledge, skills, and dispositions to spatial thinking.

STUDY ASSUMPTIONS

1. This study assumes that individuals' understandings of spatial concepts can be measured and that the spatial concepts test developed for this study is a valid instrument to measure it.
2. This study assumes that participant-produced lesson plans are a valid representation of their knowledge about and skills to teach spatial thinking.
3. This study assumes that differences between the pre- and post-test are results of the intervention.
4. This study assumes that participants' answers to the teaching spatial thinking disposition survey and interview questions accurately represent their beliefs, attitudes, and opinions.

STUDY LIMITATIONS

1. Participants were not recruited by a random sampling method. Thus, this study cannot assume that the sample is representative of a larger population, making generalizations about the conclusions limited.

2. This study did not affect participants' course grades. Therefore, participants may have perceived this study as not important to them and may not have tried as hard as possible on given tasks.

ORGANIZATION OF THE DISSERTATION

The primary purpose of Chapter I was to introduce the objectives of the study and the four operational research questions. The study context and its significance were also discussed. Chapter II reviews literature relevant to the study. It consists of three sections: 1) learning to think spatially; 2) teaching spatial thinking through geography; and 3) preparing preservice teachers to teach spatial thinking. In Chapter III, I explain the research design, methods, and procedures involved in the intervention and the assessment tools developed and used for this study. Chapter IV reports the outcome of the study in relation to the four research questions, and Chapter V provides interpretation and implications of the study.

CHAPTER II

LITERATURE REVIEW

The present research seeks to examine the effect of explicit instruction in spatial thinking on preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking. This chapter reviews literature relevant to the study. It consists of three sections. In the first section, I explain how this research conceptualizes spatial thinking by clarifying its definition and the three key components. Then, a review of research follows, exploring how students learn spatial thinking. By demonstrating spatial thinking is something that can and should be taught, the section provides a rationale for implementing spatial thinking into school subjects and instructional practices explicitly. The teachers' role in the student learning of spatial thinking is also discussed.

The second section focuses on a teacher's capability to teach spatial thinking. The importance of the teacher understanding spatial perspectives in geography is first examined. The importance of the teacher's pedagogical knowledge about the instructional strategies that better support spatial thinking is stressed next. Lastly, why developing appropriate dispositions toward teaching spatial thinking is important is discussed.

The third section reviews the literature to support a claim that teacher preparation is critical for teachers to develop such knowledge, skills, and dispositions to implement spatial thinking into their practice. I first discuss how teacher preparation affects teacher effectiveness in the classroom in general. Then, I examine the literature specifically about geography teacher preparation and identify the location of spatial thinking in the curriculum of current preservice geography teacher education. Lastly, research that provides insights into effective ways of enhancing knowledge, skills, and dispositions associated with teaching spatial thinking is reviewed.

LEARNING TO THINK SPATIALLY

Spatial Thinking

What is spatial thinking? What does it mean that someone learns or teaches to think spatially? In the present research, spatial thinking is defined as "a collection of cognitive skills comprised of knowing spatial concepts, using tools of representation, and reasoning processes," following the definition developed in the report from the National Research Council (2006, 12). This conceptualization of spatial thinking is not only broader than spatial ability, which has most often been conceptualized and discussed in the psychological research, but it is also applicable to a variety of disciplines including mathematics, sciences, and geography. While spatial ability is often restricted to represent one's capability of visualization and mental orientation, spatial thinking encompasses broader sets of interconnected competencies associated with its three key components: knowledge about space, ability to use tools of representation, and processes of reasoning (National Research Council 2006).

The first component, concepts of space are the building blocks for spatial thinking. They make spatial thinking a distinctive way of thinking by using space as a framework for understanding, structuring, and solving problems. Spatial thinking is inseparable from knowing where something is; what is there; and how it is linked with other places (National Research Council 2006). Research has pointed out that such knowledge about space could be obtained, understood, and communicated more effectively when using spatial concepts. Golledge and Stimson (1997) for example, emphasized the significance of proper uses of spatial languages for more accurate communications.

> Descriptions of the *what* and *where* of places become more or less interpretable as people choose appropriate nouns and prepositions to formalize relationship (Golledge and Stimson 1997, 414).

A number of spatial concepts can be listed, but some concepts seem particularly relevant to geography such as location, place, distance, direction, connection, movement, region, distribution, pattern, scale, and map projection. However, there have been few attempts to identify and classify spatial concepts in geography, with a handful of exceptions such as Golledge's works. Golledge (1995, 2002) defined a set of spatial primitives: place-specific identity, location, magnitude, and time; and derived a series of simple- and complex-spatial concepts from the primitives. A refined version of the concept lexicon developed by Golledge and his colleagues (Marsh, Golledge, and Bettersby 2007) categorizes spatial concepts into five levels: Primitives, Simple (first-order derivatives), Difficult (second-order derivatives), Complicated (third-order derivatives), and Complex (fourth-order derivatives). Table 1 summarizes the evolving concept lexicons in the works of Golledge and his colleagues.

Table 1. Concepts of space (from Golledge 1995, 2002; Marsh, Golledge, and Bettersby 2007).

1995		2002		2007	
First Order Primitives	Identity; Location; Magnitude; Time	Primitives	Place-specific identity; Location; Magnitude; Time	Primitives	Identity; Location; Magnitude; Time
Derived Concepts	Distance; Angle and Direction; Sequence and Order; Connection and Linkage	First Order Concepts	Distribution or Arrangement; Frames of reference; Orientation and Directions; Spatial hierarchies and Dominance	Simple	Arrangement; Distribution; Line; Shape; Boundary; Distance; Reference frame; Sequence
Spatial Distributions	Boundary; Density; Dispersion; Pattern and Shape			Difficult	Adjacency; Angle; Classification; Coordinate; Grid pattern; Polygon
		Higher Order Concepts	Pattern; Clustering and Dispersion; Spatial association; Density and Distance decay	Complicated	Buffer; Connectivity; Gradient; Profile; Representation; Scale
Higher Order Concepts	Correlation; Overlay; Network and Hierarchy			Complex	Areal association; Interpolations; Map projection; Subjective space; Virtual reality

The second component, representations, serves as an effective tool for thinking and a stimulus to complex reasoning. The skill to use and create spatial representations is central to expertise in spatial thinking (National Research Council 2006; Tversky 2005). Tools of representations, such as maps, models, diagrams, graphs, and charts, help organizing and externalizing abstract information into more understandable and, therefore, easily communicable forms (Mathewson 1999; Tversky 2005). The significant role of spatial representations as a means for effective communications has been acknowledged not only in the context of daily life but in scientific work as demonstrated by the following quotes.

> Symbolic representations of spatial location, either in linguistic description or in various kinds of visual displays, serve to communicate information gained by one person to other people, saving them the necessity of personally exploring every area they visit (Newcombe and Huttenlocher 2000, 145).

> Scientific work does not become effective science until it is communicated and subjected to public scrutiny. Science and technology develop through the exchange of information and much of this is presented as diagrams, illustrations, maps, plots, schematics, etc., which summarize the information and help others to understand it (Mathewson 1999, 37).

The influence of representations on the facilitation of spatial reasoning has also been recognized. For example, Uttal (2000) wrote:

> Using and thinking about maps may help children to acquire abstract concepts of space and the ability to think systematically about spatial relations that they have not experienced directly. In addition, exposure to maps may help children to think about multiple spatial relations among multiple locations (Uttal 2000, 247).

Lastly, it is the third component, reasoning processes, that enables knowledge about space and representations to be combined for problem solving and decision making through analysis, classification, hypothesis-making, generalization, and evaluation. Grounded in this conceptualization of spatial thinking, learning to think spatially in this research means learning processes through which one acquires knowledge of spatial concepts; learning skills to use tools of representation to remember, understand, analyze, and communicate information; and learning higher order cognitive processes to solve problems and make decisions using the knowledge and skills. Teaching to think spatially, therefore, means a teacher's explicit effort and instructional practices to facilitate students' knowledge acquisition of spatial concepts, development of skills using a variety of tools of representation, and higher level thinking processes.

The Nature of Expertise in Spatial Thinking

Exceptional Performance vs. Level of Relative Proficiency

How does a person become a spatial thinker? What are the characteristics of expertise in spatial thinking? How does expertise in spatial thinking develop? Prior to the discussion of the expertise in spatial thinking, the term expertise may need to be clarified. There are a number of definitions of expertise, reflecting somewhat different point of views on it. In the field of psychology, for example, the nature of expertise has been studied in two general ways: the absolute approach and the relative approach (Chi 2006).

Studies of absolute expertise focus on highly exceptional, remarkable people, such as eminent scientists or athletes who have won international competitions. For example, Wilding and Valentine (1994) studied a group of memory experts to examine whether superior memory skills are a result of the acquisition and use of techniques or a natural talent. Ten memory experts, including seven winners at the World Memory Championship, were categorized into either 'strategic memorizers' or 'natural memorizers,' based on their self report about the degree to which they relied on strategies in an initial memory test. Two different types of tasks were then administered: one category of tasks ('strategic tasks') included recall tests for faces, names, words, and telephone numbers, those readily amenable to techniques (e.g., mnemonic); and the other group of tasks ('non-strategic tasks') included tests for a story, spatial and temporal positions of pictures, and snowflakes, those where strategies were inappropriate or not readily available due to the novelty of tasks. The results of immediate recall tests showed that strategic memorizers performed outstandingly well on strategic tasks but little better than a control group on non-strategic tasks. Meanwhile, non-strategic memorizers performed above average and equally well on both types of tasks, being worse than strategic memorizers on strategic tasks but better than them on non-strategic tasks. In the retention test administered a week later, however, non-strategic memorizers performed better even though the tasks were all in the strategic category, indicating there is evidence for a natural component of exceptional memory despite the fact that the most striking examples of superior memory are strategy dependent. As in this study, studies taking the absolute approach focus more on eminent performers and on what makes these remarkable people so exceptional.

The relative approach, on the other hand, assumes that expertise is a level of proficiency in terms of domain-specific knowledge and skills, which one can achieve by learning and practice. Levels of proficiency are often assessed based on the expert-novice continuum, and the relative performances of experts in comparison to novices' are of interest. For instance, Hmelo-Silver and Pfeffer (2004) compared how experts and novices in aquaria represent their knowledge. The participants were asked to describe what they think fish do in an aquarium and to think out loud while drawing a picture of anything that they think is in an aquarium. The responses were coded according to statements relating to the three aspects of a system: structure (elements), behavior (mechanisms), and function. Although there were no differences between the experts and the novices in the number of statements referring to the structures, significant differences were detected in the number of statements referring to behaviors and functions, suggesting that the experts represent the deeper features whereas novices think in terms of literal features. Such differences were attributed to the amount of knowledge and experiences in the domain between the groups.

In this study, expertise is defined as a level of proficiency in terms of domain-specific knowledge and skills, taking the relative approach to the study of expertise. One advantage is that the relative approach seeks not only to describe the ways in which experts excel but to explain how experts became that way so that others can learn to become more skilled and knowledgeable. Therefore, taking the relative approach to expertise in spatial thinking would illuminate our understanding of how students learn and develop their spatial thinking skills, which is one of the most important questions of this study.

The Role of Experience and Practice

What is known about expertise in any domain is that expertise is a result of extensive understandings of knowledge and ways of thinking of the domain over time (Feltovich, Prietula, and Ericsson 2006; Hoffman and Lintern 2006). It is not an automatic result of high intelligence. Rather, becoming an expert requires significant time and practice.

As for the matter of time to become an expert, a 'ten-year' rule is often referred to. That is, even for the most talented individuals, at least ten years of experience in a domain is necessary to become an expert (Ericsson, Krampe, and Tesch-Römer 1993; Simon and Chase 1973). Depending on the domain, however, the necessary time can be extended or shortened. For example, elite musicians require close to 20 to 30 years of training and often peak when they are around 30 to 40 years old (Ericsson 2006). In addition, outstanding scientists and authors normally published their first work in their mid 20s, and their best work often follows around ten years later (Raskin 1936). An example of shorter-than-ten-years is that memory experts typically reach the highest level in the world after less than a couple of years training (Ericsson 2003). Despite the varying degree, the necessity of years of domain-specific experience to become an expert is generally understood.

Research also emphasizes the importance of practice in developing expertise. Practice in this context, however, should not be understood as the same as mere repetitions of routine performance. Rather, research evidence indicates that only practice that is carefully designed and guided by a teacher or coach with a purpose of optimizing improvement of current performance makes a difference. For example, Ericsson, Krampe, and Tesch-Römer (1993) compared groups of violinists in terms of their time spent on a variety of violin-related activities. The analysis of weekly diaries of the participants revealed that even among elite performers, individual differences in performance were closely related to the amount of effortful practice, in which specific tasks were executed to improve the performances. The significance of purposeful practice is also found in a study by Grape et al. (2003). They compared professional singers and amateurs in the level of physiological and psychological indicators of concentration and effort during a singing lesson. The result showed that the professional singers were clearly achievement-oriented and focused on improving their singing technique during the lesson. Meanwhile, the amateur singers experienced the lesson as a means of self-actualization and self-expression as a way to release emotional tensions. Guided practice is important to develop expertise in teaching. Binko (1989) stressed the significant role of guided practice in developing teachers' ability to incorporate new ideas and skills for teaching into practice. According to him, the level of skill and confidence that teachers need for an effective implementation of the new ideas to their own classrooms cannot be achieved unless they had sufficient opportunities to practice the skills they have been introduced to. It is important that teachers should practice such skills in an environment where they can receive immediate feedback on their progress from teacher educators, peer teachers, or mentors.

With expertise in any other domains, superior performance in spatial thinking also requires years of experience and practice. Charness et al. (2005) surveyed over 400 tournament-rated chess players and estimated the frequency and duration of their engagement in a variety of chess-related activities. Analyses of a series of regressions revealed that among the activities measured, deliberate practice was the strongest predictor of chess skill. Actually, chess players at the highest skill level (i.e., grandmasters) spent about 5,000 hours on deliberate practice during their first decade of serious chess play whereas the average amount reported by intermediate-level players was about 1,000 hours. A review of research by Durso and Dattel (2006) provides a good summary of characteristics of transportation experts, often considered requiring a high level of spatial ability. In general becoming an expert in driving required at least five years, 4,000 hours, or 40,000 miles of driving experience. Exceptionally high levels of performance, however, necessitated explicit training and task-specific practice in addition to lengthy experience.

Domain Specificity

It is also well known that expertise is domain-specific. That is, experts in a specific domain, for example history, do not necessarily show comparable fluency or depth of thinking in other domains, saying mathematics. Likewise, expertise in spatial thinking is domain-specific. The National Research Council's report explicitly mentions domain specificity as a main characteristic of expertise in spatial thinking:

> Experts in one application of spatial thinking, such as architecture, may not find those skills useful in another application of spatial thinking, such as interpreting weather maps, because the representations and their underlying scientific principles are different (National Research Council 2006, 104).

In summary, at least two generalizations about the nature of expertise in spatial thinking are relevant to this study: 1) developing expertise in spatial thinking takes substantial time and practice; and 2) the knowledge and skill acquisition and guided practice to develop spatial thinking skills should occur within the context of a specific domain, for example, geography, mathematics, physics, and so on.

Development of Spatial Thinking in Schools

Despite knowledge about the nature of spatial thinking and recent recognition of its importance not only in contemporary workplaces and the sciences but in students' academic success (National Research Council 2006; Ramadas 2009; Solem, Cheung, and Schlemper 2008), few studies inform how to promote spatial thinking in the current education system. As the report by the National Research Council (2006), *Learning to Think Spatially*, pointed out, the question of what kinds of experiences contribute to students' learning to think spatially has not been precisely answered.

Spatial thinking is not a completely novel idea. In various disciplines spatial thinking has been studied. Cognitive psychologists have long investigated age-related development of spatial cognition. Research on the development of spatial cognition with age – naturally emerging or incidentally learned spatial understanding – are quite abundant. Some of the key findings from such studies include that: 1) although underlying mechanisms are disputable, it is generally accepted that overall, precision of coding and organizing locations increases with age (Newcombe and Huttenlocher 2000; Spencer and Plumert 2007); 2) one's ability to form and use spatial categories is enhanced with age (Huttenlocher, Newcombe, and Sandberg 1994; Sandberg, Huttenlocher, and Newcombe 1996); and 3) despite high variability among adults, in general, understanding of maps as a representation of spatial relations increases with age (Liben and Myers 2007).

Behavioral geographers, on the other hand, have focused more on individuals' behavioral and decision making patterns in a relatively large space – geographic space (Bednarz, Downs, and Vender 2003; Golledge and Stimson 1997; Hanson 1976). In the mean time, the main interests of educational psychologists have been in the identification of factors that underlie one's spatial ability. The purpose was primarily to develop spatial ability tests and identify sources of individual or group differences in performances on those tests (e.g., Anastakis, Hamstra, and Matsumoto 2000; Kail and Park 1990; Lohman and Nichols 1990; Lord 1985; Quaiser-Pohl and Lehmann 2002).

Relatively less attention has been paid to the development of spatial thinking through interactions with and interventions through school learning. There exist studies that demonstrated the effect of training in the development of certain spatial skills. These studies are well summarized and synthesized by Baenninger and Newcombe's (1989) work. In a meta-analysis of previous studies, they found that for both males and females, training positively influenced participants' performances, especially when it was test-specific and the duration of the training was at least three or four sessions. Research by Kail and Park (1990) examined training effect on performance on mental orientation tasks. Results of experiments with three different age groups (11, 20, and 30 year olds) revealed that training had a positive impact on participants' performance. The research findings regarding the development of spatial thinking through learning and training, however, have not been synthesized so that they can provide insights on the design of curriculum to facilitate students' spatial thinking skills in the context of a variety of school subjects.

Nonetheless, there is emerging research that provides some insights into the types of learning experiences that can positively affect the promotion of students' spatial thinking skills. For example, map use has long been emphasized as a way to develop one's spatial thinking skills (Davies and Uttal 2007; Tversky 2000; Uttal 2000). Available evidence is consistent that exposure to and use of maps can contribute to enhancing spatial cognition. For example, Uttal and Wellman (1989) investigated the effect of map learning on children's ability to learn a route in a space (a large playhouse in this case). One group of children learned a map of the playhouse before entering it while the other group did not. The results showed that children who learned the map learned a route more quickly than those who were not exposed to the map. The reason for the positive effect of map learning on enhancing one's spatial cognition seems not just because of having seen the exact location of each feature on the map. According to Uttal, Fisher, and Taylor (2006), it may also be related to the opportunity to learn the outline of the overall configuration. In another experiment with eight-year-old children, Uttal, Fisher, and Taylor (2006) demonstrated that those who saw only the outline map and then heard the descriptions of the features performed almost as well as those who learned from a complete map, indicating that maps facilitate spatial cognition by providing a frame of reference to encode spatial relations.

Academic course work in Geographic Information System (GIS) proves helpful to enhance students' spatial thinking skills. Research by Lee and Bednarz (2009) exemplifies the positive impact of GIS course taking on the development of college students' spatial ability, particularly related to understanding spatial relations. A spatial-skills test was administered to students enrolled in different geography courses – GIS, cartography, and economic geography – and their performance on the test at the beginning and end of the semester were compared. The significant score increase between pre- to post-tests was observed only in the GIS group, and there were strong correlations between the participants' spatial thinking skills and their achievement in the GIS course. The researchers attributed the improvement of students' performance on the tasks to the nature of GIS, which inherently enables the user to better examine and understand spatial relations.

Research also shows that using geospatial technologies as an instructional tool can be effective to enhance students' spatial thinking skills. For instance, Bodzin (2011) developed a geospatial technology-supported science curriculum and examined whether the curriculum implementation contributed to enhanced students' knowledge and skills. The results of pre- and post-assessments, classroom observations, and teacher interviews indicated that using geospatial technology as a teaching and learning tool was effective for improving spatial thinking skills involved with remotely sensed image interpretation. Another example is a qualitative study by Milson and Curtis (2009) conducted in the context of social studies. They analyzed features of MyWorld GIS software, developed a classroom module associated with a site selection analysis task using the software, and tested the module in a classroom. The students' responses and classroom observations during the lesson indicated that the tool facilitated students in practicing spatial thinking skills.

Besides taking a GIS course or using geospatial technology, studies report that certain student activities and classroom tasks also support spatial thinking. For example, Hooey and Bailey (2005) examined the effect of journal writing on students' geography learning. They compared college students' overall performances in a world geography course between groups of students enrolled in writing-intensive sections and those in regular sections. Over a period of three years, the average final grade of eleven sections where students were engaged in journal writing as part of the course requirement was significantly higher than that of eight sections where no journals were required. The authors suggested that reflections on their own learning through journal writing facilitated students' spatial thinking by helping them learn about different places, cultures, and perspectives, and by giving them opportunities to synthesize the relationships between people, places, and systems on their own words. Another example in mathematics education illustrates the effect of teaching with blocks on engaging students in activities that address spatial thinking. Based on classroom observation and conversation with teachers and students, Taylor-Cox (2009) found that manipulating blocks and engaging mathematical conversations about the locations and spatial relations of the blocks facilitated children's learning of spatial vocabulary.

> Using words to describe relative block position (above, below, besides, under) is beneficial. Likewise, using words to express order (before, after, between) builds understanding of spatial relationships (Taylor-Cox 2009, 463).

As illustrated in the examples above, research exists to inform the kinds of courses, materials and technologies, and student activities that work well for the development of students' spatial thinking. The insights learned from such studies are valuable to support spatial thinking through the school system. However, none of these studies explicitly mentioned the teachers' role, capability of, and willingness to incorporate these innovative materials and activities into the classroom. Without classroom teachers' awareness and efforts to implement spatial thinking, spatial thinking will not be taught effectively. It cannot be assumed that teachers will automatically be able to adopt such innovative materials and curricula into their practices.

The Teacher's Role

The role of teachers in promoting students' learning is well documented in education research. It is commonly accepted conceptually, probably better than empirically, that teachers play an important role in student learning. For example, teachers are often viewed as curricula-instructional gatekeepers, who construct the curriculum that is actually provided in the classroom (Thornton 1989, 2001b). That is, teachers are those who make crucial decisions concerning content, sequence, and instructional strategies that determine the students' learning experiences. As Adler (2008) states:

> Teachers are far more than mere conduits of information or of curriculum developed by experts … They, along with their students, are the implementers of the actual curriculum (Adler 2008, 329).

Leander and Osborne (2008) made a similar point that:

> All teachers select and develop their curricula for some audience; all teachers find themselves within complex relationships to other staff and students; and all teachers, even the most isolated, respond to these real and imagined audiences within the constructive act of classroom teaching/curriculum development. To teachers, this perspective is not particularly surprising (Leander and Osborne 2008, 43).

Empirical evidence also supports the claim that good teachers make the difference. A large-scale quantitative study to examine the significance of teacher quality was conducted by Darling-Hammond (1999). She used state-level data of teacher characteristics, other school resources, and student achievement to examine how teacher qualifications and other school factors relate to student achievement. Student achievement data of 44 states examined were from the National Assessment of Educational Progress (NAEP) during the years of 1990 to 1996, and data on indicators of teacher preparation, class sizes, and other school resources were based on the national Schools and Staffing Survey (SASS). After controlling for student poverty and language background in reading, the strongest and most consistent predictor of a state's average student achievement was the proportion of well-qualified teachers in the state. More specifically, the teacher quality variables accounted for approximately 40 to 60 percent of the total variance across states in average student achievement levels on the NAEP 4th and 8th grade reading and mathematics assessment.

Hanushek and his colleagues have conducted a series of studies on the topic of teacher quality and student achievement. In one of these, they analyzed data from over a million students and 3,000 schools in Texas and found powerful effects of teachers on students' achievement (Rivkiin, Hanushek, and Kain 2005). Based on longitudinal information on individual students' test scores in reading and mathematics for three different cohorts, they estimated the contribution of differences in teacher quality to student learning. Regression analyses generated sizable estimates of the teacher quality variance, and according to the result, moving from an average teacher to one at the 85th percentile of teacher quality (i.e., moving one standard deviation up in teacher quality distribution) increased student achievement gains by more than four percentile ranks in the given year. The authors argued that the benefit of improving teacher quality was larger than the effect of a ten student decrease in class size, emphasizing the importance of teacher effectiveness.

Studies have also provided evidence that even in the non-conventional, student-centered pedagogies, such as inquiry-based and collaborative learning, the role of a teacher is never diminished. Viilo, Seitamma-Hakkarainen, and Hakkarainen (2011) conducted a qualitative study to examine the teacher's role in implementing a science inquiry curriculum into the classroom. An experienced teacher participated in the study, adapted the lesson plan into her classroom teaching, and wrote weekly diaries to reflect on her own practices. The content of the diary was analyzed to reveal how the teacher instructed and supported students in inquiry activities. The result suggested that even with well-structured curriculum that could guide students to engage in inquiry processes on their own, teachers' invisible work and ability to guide students to participate in inquiry activities remained important. Often times, the teacher needed to rely on her own subject-domain knowledge and skills to effectively implement the curriculum into the classroom context. What this study indicates is that although the teacher's role required in these relatively new modes of learning is different from the traditional teacher-driven instructional practices and, therefore, changing, the importance of teacher's role in student learning remains significant. Viilo, Seitamma-Hakkarainen, and Hakkarainen (2011) concluded:

> The role of a teacher is changing. New kinds of pedagogies require teachers to function more like managers of knowledge-intensive companies than simple distributors of knowledge ... When the aim is to facilitate students' know-how in collaborative inquiry, the teacher has to cultivate in his or her classroom certain practices of working with knowledge, including the conceptual and material artifacts involved ... The teacher is in a crucial position in engaging students in this kind of inquiry culture and community, exploiting available technological and knowledge resources (Viilo, Seitamaa-Hakkarainen, and Hakkarainen 2011, 69).

Thus, the examples described above can be summarized as: "[a]mong all educational resources, teachers' abilities are especially crucial contributors to students' learning" (Darling-Hammond 2006b, 300); and "teacher quality if one of the most significant school influences on student achievement" (Miller 2009, 1).

Considering the primary structuring role of the teacher in the classroom and the role as a facilitator and cultivator of a sound learning community, spatial thinking may not be infused into the classroom effectively until teachers understand the importance of spatial thinking, are equipped with required knowledge and skills, and become willing to incorporate it into their practices. There is no study that conceptualizes teacher characteristics associated with teaching spatial thinking. Nothing is known about teacher effectiveness related to teaching spatial thinking, which is not surprising. The dearth of research may be attributed to the fact that spatial thinking has not been appreciated and recognized in education until recently (National Research Council 2006), and that only now are educators recognizing that spatial thinking is an important component of student learning (Bednarz and Bednarz 2008).

Summary

In this study, spatial thinking is defined as a collection of cognitive skills comprised of knowing concepts of space, using tools of representation, and processes of reasoning. Learning to think spatially, in this study, is defined as learning processes through which that one acquires knowledge of spatial concepts; learning, skills to use tools of representation to remember, understand, analyze, and communicate information; and learning higher order cognitive processes to solve problems and make decisions using the knowledge and skills. Teaching to think spatially can, therefore, be conceptualized as a teacher's explicit effort and instructional practices to facilitate students' knowledge acquisition of spatial concepts, development of skills using a variety of tools of representation, and higher level thinking processes.

The literature reviewed in the study provides at least two generalizations about the nature of expertise in spatial thinking: 1) developing expertise in spatial thinking takes substantial time and deliberate practice; and 2) the knowledge and skill acquisition and guided practice to develop spatial thinking skills should occur within the context of a specific domain. The implications are clear: spatial thinking should be incorporated throughout the K-12 education, and students must be given opportunities to deliberately practice this important thinking skill while learning subject matter knowledge and skills.

Research exists to inform the kinds of courses, materials and technologies that work well for the development of students' spatial thinking. Spatial thinking may not be infused into the classroom effectively, however, until teachers understand the importance of spatial thinking, are equipped with required knowledge and skills, and become willing to incorporate it into their practices. This is because the teachers are those who implement the curricula, materials, and technologies into the classroom context; design students' concrete learning experiences; guide their practices; and evaluate their performances. There is no study that conceptualizes teacher characteristics associated with teaching spatial thinking. Little is known about teacher effectiveness related to teaching spatial thinking, either.

In the next section, I review the literature that can help conceptualize the teacher characteristics associated with teaching spatial thinking, focusing on the teacher's knowledge, skills, and dispositions. The ultimate purpose of this study is to develop students' spatial thinking while learning geography, so the discussion is contextualized in teaching spatial thinking through geography.

TEACHING SPATIAL THINKING THROUGH GEOGRAPHY

The theory of pedagogical content knowledge by Shulman (1986, 1987) has been influential in accounting for what effective teaching requires. This also provides a useful framework to conceptualize teacher requirements for effective teaching of spatial thinking. Shulman (1987) identified a list of the knowledge and skills teachers need to teach subject matter effectively. This list includes: 1) content knowledge; 2) general pedagogical knowledge; 3) curriculum knowledge; 4) pedagogical content knowledge; 5) knowledge of learners and their characteristics; 6) knowledge of educational contexts; and 7) knowledge of educational ends, purposes, and values, and their philosophical and historical grounds. Among these, content knowledge and pedagogical content knowledge seem worth more attention as they are directly related to teaching spatial thinking in the context of the subject of geography.

Content knowledge refers to “the amount and organization of knowledge per se in the mind of the teacher” (Shulman 1986, 9). It is content knowledge that enables teachers to “define concepts and accepted truths in a domain” (Shulman 1986, 9) and to “explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions” (Shulman 1986, 9). In the context of teaching spatial thinking with geography, a teacher’s content knowledge can be conceptualized as knowledge about the subject matter of geography and knowledge about spatial thinking as a way of thinking used both within the discipline of geography and outside of it.

Pedagogical content knowledge refers to “the subject matter knowledge for teaching,” (Shulman 1986, 9) which is a “special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding” (Shulman 1987, 8). Pedagogical content knowledge is knowledge about the best way to teach subject matter. Shulman described it as, “an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them” (Shulman 1986, 9). It is “the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations and demonstrations – in a word, the ways of representing and formulating a subject that makes it comprehensible to others" (Shulman 1986, 9). Thus, pedagogical content knowledge for teaching spatial thinking can be defined as the teachers' ability to represent geographic concepts and ideas in a way to promote students' spatial thinking skills.

Given this operational definition of a teacher's content knowledge of teaching spatial thinking with geography, as knowledge about the subject matter of geography and knowledge about spatial thinking as a way of thinking used both within the discipline of geography and outside of it, it seems essential that teachers understand the spatial perspectives of geography to be able to incorporate spatial thinking into geography classrooms. Spatial perspectives of geography have long been emphasized in geography literature, and I will discuss it in the first subsection. Little research exists, however, that helps envision pedagogical content knowledge of spatial thinking, defined in this study as the teachers' ability to represent geographic concepts and ideas in a way to promote students' spatial thinking skills.

There are a few studies, however, that inform effective instructional strategies to enhance students' spatial thinking skills although they are not necessarily in geography contexts. These strategies may be considered pedagogical knowledge of spatial thinking, and I will review them in the second subsection.

Despite the usefulness of Shulman's framework to conceptualize knowledge and skills required to teach spatial thinking, there seems to be a missing component. Recent research on teacher education points that knowledge and skills are not sufficient by themselves to be an effective teacher because having required knowledge and skills to teach something does not guarantee the inclination to do so (Dottin 2009). No research has examined dispositional characteristics of teachers associated with teaching spatial thinking, however, partly because of the novelty of the concept. In the last subsection I will discuss the concept of disposition in a broad sense and speculate on how it can be defined in the context of teaching spatial thinking.

Content Knowledge: Geographic Expertise and Spatial Thinking

Teachers should understand how geography as a school subject can contribute to the development of spatial thinking. It is well known that spatial thinking lies at the center of geographic knowledge and ways of thinking (Bednarz 2006; Bednarz, Downs, and Vender 2003; Downs 1994; Geography Education Standards Project 1994; Gersmehl 2005; Golledge 2002; Liben 2006; National Research Council 2006). Geography concerns the spatial perspective and analysis, and geographers have long thought that spatial reasoning and spatial representations were distinctive features of the discipline. As Pattison (1970) said, the major goals of geography are to describe and to explain not only the character of places and areas but spatial arrangements – positions, layout, and movement of things in space. It would be relevant to examine the meaning, nature, and characteristics of geographic expertise to see the relevance of learning geography to the development of spatial thinking skills. Although there is little research wholly dedicated to identifying characteristics of geographic expertise, many geographers have speculated on what is unique to geographic expertise, differentiated from other disciplines. For example, Sauer used the term "the morphologic eye, a spontaneous and critical attention to form and pattern" (Sauer 1956, 290) to represent a unique feature of geographic expertise.

The National Geography Standards: *Geography for Life* (1994) described the characteristics of expertise in geography, using the term 'geographically informed person.' A geographically informed person is defined as "someone who understands that geography is the study of people, places, and environments from a spatial perspective, someone who appreciates the interdependent worlds in which we all live (Geography Education Standards Project 1994, 29). What the notion of 'geographically informed person' indicates is that expertise in geography is very much related to an understanding of space. As stated in the Standards:

> Space is the environmental stage upon which the domain of geography is played out, and places are particular points on the environmental stage where the actions occurs … Geography is concerned with understanding the spatial dimension of human experience (Geography Education Standards Project 1994, 31).

Downs (1994) asserted that geographic expertise appears in: 1) pattern recognition ability; 2) problem representation; and 3) procedural knowledge. An example that he provided for the ability to recognize patterns is "recognizing the interaction on a map among surficial drainage patterns, topography, and underlying geology such that inferences can be drawn about the structural genesis of the landscape forms" (Downs 1994, 180). In addition, an expert in geography would represent a problem in a more systematic way than a novice would. For example, geographic experts would see the difference between seasonal changes in weather at a place not only in terms of the surface phenomena such as high and low temperatures, amounts of rainfall, etc. but also based on his/her understandings of the underlying climatological systems, Earth-Sun relations, seasonality, etc. He also emphasized that a geography expert should possess procedural knowledge, defined as "ability to know how to use his/her geographic knowledge and skills appropriately" (Downs 1994, 180).

Golledge (2002) emphasized knowledge *about* space and geographic reasoning as key features of geographic expertise. According to him:

> Knowledge *about* space consists of the recognition and elaboration of the relations among geographic primitives and the advanced concepts derived from these primitives (such as arrangement, organization, distribution, pattern, shape, hierarchy, distance, direction, orientation, regionalization, categorization, reference frame, geographic association, and so on) and their formal linking into theories and generalizations (Golledge 2002, 1).

He also argued that not only geographic knowledge but the ways of thinking and reasoning that geographers practice are highly spatial. From an extensive review of the literature, a lengthy but unique list of thinking and reasoning processes that comprises geographic thinking and reasoning was provided. Understanding spatial concepts and spatial phenomena were particularly emphasized. Examples of geographic reasoning associated with understanding spatial concepts include: comprehending scale transformations; comprehending spatial association; comprehending orientation and direction; comprehending spatial shapes and patterns; comprehending locations and places; and comprehending overlay and dissolve. Examples of geographic reasoning related to understanding general spatial phenomena include: comprehending distance effects; comprehending spatial change and spatial diffusion; comprehending densities and density decay; comprehending integration of geographic features represented as points, networks, and regions; comprehending proximity and adjacency and their effects; and recognizing spatial forms.

Hanson (2004), on the other hand, used the term ‘geographic advantage’ – a phrase indicating what geographers do and offer that others do not – to convey the importance of geography and to communicate the identity of geographers with non-geographers. According to her, geography experts are those who have an understanding of: Relationships between people and the environment; The importance of spatial variability (the place-dependence of processes); Processes operating at multiple and interlocking geographic scales; and The integration of spatial and temporal analysis (Hanson 2004, 720). Again, understandings of space and place are important keys to geographic knowledge.

According to Goodchild (2009), the essence of geographic expertise lies not on the ability of geographic observation but on reasoning ability beyond the observation. He said:

> [T]he professional geographer is distinguished by his or her ability to reason beyond observation to develop new generalizations and theories, to test theories by comparing their predictions to observations, and to possess the sophisticated analytic tools needed to reveal insights that are not immediately apparent (Goodchild 2009, 92).

Because such reasoning is often assisted by spatial perspectives and tools, such as GIS, knowledge and skills of using those tools and techniques are considered a critical feature of geographic expertise.

A common thread throughout these terms and descriptions is that to become a geographically informed and competent person requires knowledge of spaces, geographic skills, and the ability to apply spatial and ecological perspectives to solve problems. The literature suggests that pattern recognition and spatial representation of problems are at the center of geographic thinking, reasoning, and problem solving skills, and thus constitute a major part of geographic expertise. Therefore, although the case that all geographic knowledge is spatial is disputable (Golledge 2002), there is no doubt that the way geographers look at the world and reason is highly spatial. Figure 2 represents the relationship of geographic knowledge and skills to the three key components of spatial thinking. Considering the aspects of spatial thinking embedded in geographic knowledge and skills, it is reasonable to conclude that learning to think geographically would contribute to the development of students' spatial thinking skills (Gregg and Leinhardt 1994; National Research Council 2006). In actuality, fostering a generation of spatially literate students has been one of the main goals of geography education. Spatial thinking is a novel yet foundational geographic skill that can and should be fostered in schools (Jo, Bednarz, and Metoyer 2010). It is evident that geography can be an effective vehicle to teach spatial thinking in schools. Geography teachers need to understand spatial concepts and perspectives in geography.

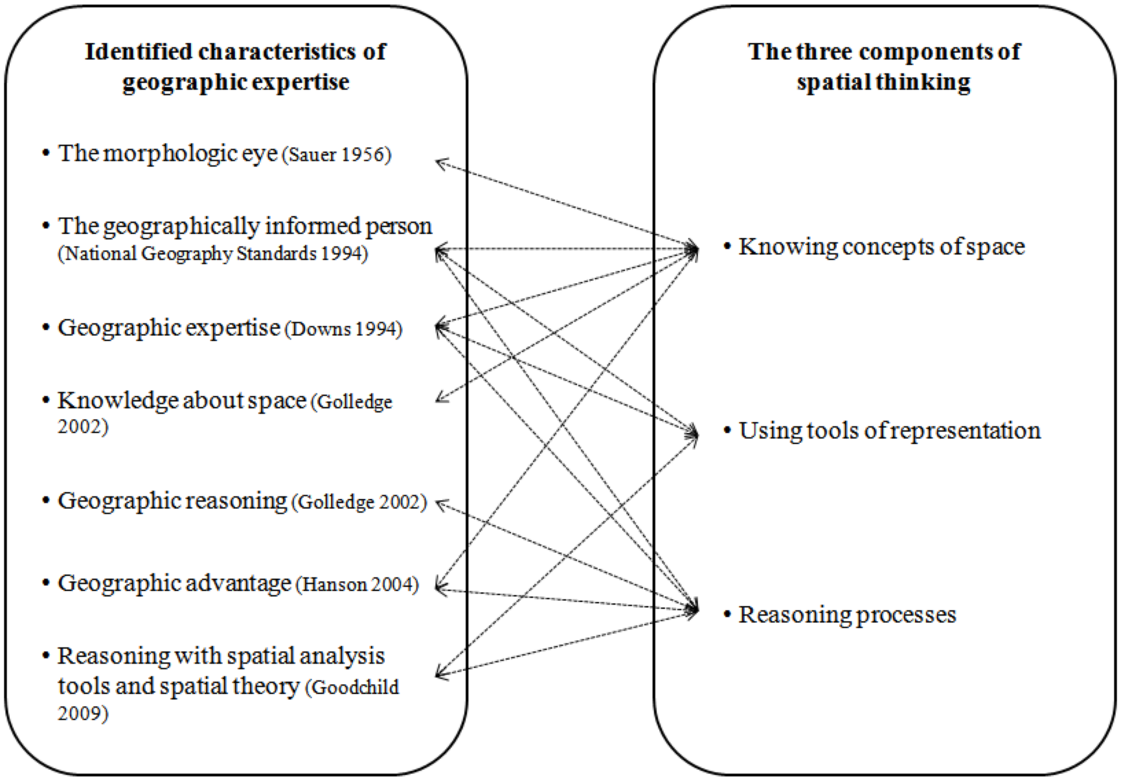


Figure 2. Geographic expertise and spatial thinking.

Pedagogical Knowledge: Instructional Practices that Facilitate Spatial Thinking

Then, how can spatial thinking be taught in a geography classroom? What kinds of instructional practices in geography would facilitate the development of students' spatial thinking skills? Although the development of spatial thinking skills has been recognized as an important goal in education, there is little empirical evidence to help teachers decide how to teach in ways that enhance students' spatial thinking skills.

Some insights can be found, however, in the literature including a review by Newcombe (2010). Based on an examination of findings from the previous research, she made some suggestions on how to improve students' learning particularly in STEM (science, technology, engineering, and mathematics) disciplines through the improvement of spatial thinking skills. Emphasizing the importance of formal instruction of spatial thinking especially after preschool, she provided a list of effective instructional strategies that teachers can use to facilitate students' spatial thinking. These include: 1) Highlight spatial elements in mathematics lessons (e.g., measurement); 2) Add mapping skills, when possible, to geography lessons; 3) Use well-crafted analogies [representations] so that comparisons will highlight essential similarities and differences (e.g., diagrams of animal and plant cells); 4) Ask children in upper elementary and middle school to make sketches to elaborate on their understanding of topics (adapted from Newcombe 2010, 34-35). Each of the instructional strategies listed above that are known to be effective to enhance students' spatial thinking skills is associated with one of the two categories: 1) using and creating a variety of spatial representations (e.g., map skills, use of diagrams, and making sketches to illustrate own understanding); and 2) explicit teaching of spatial vocabularies and concepts (e.g., highlighting spatial elements in the subject, measurement in mathematics for example). Empirical evidence also supports that these instructional practices are effective to facilitate spatial thinking in classrooms.

Use of Spatial Representations

It is well known that spatial representations, such as maps, diagrams, and graphs, have the potential function to help students in learning and problem solving (Pape and Tchoshanov 2001; Shah, Mayer, and Hegarty 1999; Tversky 2001), and the ability to use and create spatial representation is one of the key components in spatial thinking (NRC 2006). Therefore, it is reasonable to expect that incorporating a variety of spatial representations into instructional practices would facilitate the development of students' spatial thinking.

Merely showing representations to students does not seem to facilitate students' learning, though. What research often suggests is that students benefit from creating their own representations more than from just reading or interpreting representations. For example, Kolloffel et al. (2010; 2011) conducted experiments to examine the effect of creating representations (e.g., a concept map) on student learning in mathematics. The results showed that the construction of representations, in which students express their domain understanding, significantly improved their knowledge. Sorby (2009) found that sketching practice contributed to the development of students' three-dimensional spatial skills more than other factors, such as time of exposure, the amount of direct instruction, and the use of the multimedia software. A study by Stern, Aprea, and Ebner (2003) found that constructing a graphic representation also contributed to knowledge transfer. In their experiment, one group passively encountered a linear graph, while the other group was asked to actively construct this graph following the instructions provided. The results showed that constructing a graphical representation fosters cross-content transfer from one content area to another in economics. The reason is, according to the authors, probably because by constructing graphs, learners may become aware of the representational elements onto which specific content information can be mapped.

It should be noted, however, that it is important that the teacher provide students with meaningful contexts and opportunities to communicate with the teacher and peers about the purpose and effectiveness of the representations they are producing. For example, Vellom and Pape (2000) examined students' skills of using and creating graphic representations as a means to communicate with others. Twelve high school students were asked to produce graphic representations of a dataset to inform other students, and the representations they produced at the beginning and at the end of the institute were compared. It was observed in the pre-representations that many of them lacked relational features, which is the key to understanding of the representation or the data. It was likely that students perceived this task as a typical school task, the purpose of which was to draw a picture of the data, without regard to the inferences that might be drawn from the data. That is, they viewed the representations as end results rather than tools for argumentation or illustration of relationships. What was recommended for teachers is to provide contexts in which students are challenged to construct representations of data in order to instruct other students about complex natural phenomena. Opportunities to communicate their understandings, to debate them, and to propose and conduct new tasks that they engender should also be provided.

It seems that appropriate scaffolding and guidance from the teacher in activities using and creating spatial representations are important in order for these activities to be as effective as intended. As Meira (1995) asserted, from analyses of classroom observations, videos of problem solving sessions, and interviews with students, the meaning and usefulness of representations for problem solving is not a static entity.

Rather, the initial representations students produced and their evolution depend on the purpose for creating the representations, the classroom discussion that surrounds the presentation of these representations, and the instructional practices in which the teacher engages the students. That is, the educational effect of activities involving spatial representations may vary, depending on how the teacher organizes the activity and scaffolds students to engage in the activity in a more meaningful way. The essence concerns not just whether to use spatial representations in class but when, where, and how to implement them into a variety of teaching and learning practices through which students can practice spatial thinking effectively.

Explicit Teaching of Spatial Concepts

Although hard evidence is lacking that explains a direct relationship between learning spatial concepts, or vocabularies, and the enhancement of one's spatial thinking skills, findings from previous research suggest that a person's spatial cognition is influenced by spatial language and vocabulary that he or she develops. One of the recent cross-linguistic studies has well demonstrated this relationship. Choi (2006) examined how English and Korean infants' sensitivity to specific spatial relations changes as they develop spatial vocabulary in their languages. She compared sensitivity of infants at various ages (18 to 36 months) to a distinction between tight-fit and loose-fit containment relations, which is systematically made in Korean ('kkita': fit tightly) but not in English ('in': fit either tightly or loosely). The results showed that while English learners weakened their sensitivity to the distinction by 29 months of age, Korean learners maintained high sensitivity to the distinction throughout the age periods tested

(29 and 36 months). This weakened sensitivity among English learners was hypothesized as a result of their learning of vocabulary ‘in’, which refers to containment regardless of tight-fit or loose-fit. Indeed, the language surveys filled out by the mothers showed a significant increase between 24- and 29-month-old English learners in the percentage of children who productively used the spatial word ‘in’. Strong sensitivity of Korean learners to the tight-fit relationship was, therefore, attributed to their explicit learning and using of spatial vocabulary that depicts such a specific spatial relationship.

Researchers also reported that students’ lack of spatial vocabularies often hinder their learning. From the years-long project aimed to implement spatial thinking skills in K-12 science and social studies classrooms, *Advancing Geospatial Skills in Science and Social Science* (AGSSS), Bednarz and Bednarz (2008) found many students had difficulty in understanding given tasks as well as communicating what they learned with others because they lacked adequate spatial vocabulary required for doing that. Although this finding may not prove a causal statement that one’s enhanced spatial vocabulary will improve his or her spatial ability, it definitely supports a claim that adequate knowledge of spatial concepts would facilitate the learning process.

Explicit Instruction on Spatial Thinking

It is not known whether explicit instruction in spatial thinking enhances students’ spatial thinking skills, but a positive effect of explicit instruction is expected based on the literature on teaching thinking skills, such as critical thinking. It seems that traditionally, the imbedded approach to teaching thinking skills, where teachers have tried to facilitate students’ thinking without direct instruction in the language and exercise of the thinking skills, has been preferred to the explicit approach, where teachers explicitly address specific concepts and topics in that specific type of thinking (Marin and Halpern 2011). Recent studies, however, report the superior effectiveness of explicit instructions to imbedded ones. For example, Marin and Halpern (2011) compared the effect of explicit and embedded instructional modes to enhance high school students' critical thinking skills. Students in the explicit instruction group participated in a workshop that explicitly addressed specific topics in critical thinking while those in the embedded instruction group participated in a course that covered the same topics but delivered them in a more implicit manner. The results showed that the students who received explicit instruction gained much more than those in the embedded instruction group.

The merit of explicitly addressing thinking skills in teaching is also confirmed by van der Schee, Leat, and Vankan's (2006) study. The effect of *Thinking Through Geography* (Leat 1998; Nichols and Kinninment 2001) strategies, where some of the fundamental concepts and important cognitive skills in geography were explicitly addressed, on thinking skills of students in lower secondary education was examined. The pre- and post-test results between experimental- and control-groups among different schools were compared, and there was a significant increase in the experimental groups' post-test scores. However, big differences between the schools were detected. Analysis of classroom video indicated that the differences could be attributed to the differences between teachers in the amount of attention given to thinking skills processes and their ability to manage open-ended discussion and debrief the strategies, which can be an indicator of the teacher's pedagogical content knowledge of teaching thinking skills.

Dispositions toward Teaching Spatial Thinking

Recent literature on teacher education points that knowledge and skills are not sufficient by themselves to prepare teachers because having required knowledge and skills to teach something does not guarantee the inclination to do so (Dottin 2009). For example, the degree to which a teacher incorporates spatial thinking into their daily practices will vary, depending not only on the level of their knowledge and understandings of spatial thinking but on dispositions toward teaching it. Focus on teacher dispositions has increased for the last decade particularly due to the inclusion of it in the accreditation and professional standards for teachers, such as the standards of the National Council for Accreditation of Teacher Education (2002) and the standards of the Interstate New Teacher Assessment and Support Consortium (1992) (Dottin 2009; Stooksberry, Schussler, and Bercaw 2009).

Despite increasing attention and emphasis, there is a lack of consensus on what is really meant by disposition (Diez 2007; Stooksberry, Schussler, and Bercaw 2009). Varying definitions sometimes reflect fundamentally different views. For example, some people believe that dispositions are static so largely unchangeable whereas others view dispositions as malleable, and thus, things that can and should be shaped. Some researchers relate dispositions only to observable behaviors and actions (Katz and Raths 1985) while others view dispositions as a characteristic that goes beyond external behaviors to internal characteristics, such as awareness, inclination, and beliefs (Dottin 2009; Oja and Reiman 2007; Schussler 2006; Stooksberry, Schussler, and Bercaw 2009; Villegas 2007).

This study follows conceptualizations of dispositions as a teacher's characteristic, both external and internal, that can affect instructional decision making and professional judgment. Teacher dispositions are viewed to be operating "as both a point of convergence, representing filter through which a teacher frames his/her thinking and behaviors, and a point of inception, from which knowledge and behaviors emanate" (Schussler 2006, 259). In this study, the term disposition is used to express the underlying motivator and organizer of a teacher's instructional behaviors (Ritchart 2002), which include beliefs, awareness, and inclinations. Under such conceptualizations, developing teacher dispositions would be a matter of enhancing teachers' awareness of, inclinations toward, and reflections on what they teach and how they teach it. Teacher dispositions toward teaching spatial thinking, therefore, can be defined as a teacher's awareness of spatial thinking as an important thinking skill, beliefs that spatial thinking can and should be taught, and inclinations to incorporate spatial thinking into the class in an explicit manner. No previous research indicates a teacher's dispositional characteristics that are specifically related to spatial thinking or even to geography. No measurement tool is available to assess the degree to which a teacher is aware of spatial thinking as an important skill and inclined to incorporate it into his/her classrooms. It is also unclear how teachers can develop dispositions through a teacher preparation program.

Summary

Research suggests that teachers' adequate knowledge, skills, and dispositions are necessary for any novel idea and innovation in education to be implemented successfully. In order for spatial thinking to be taught in geography classes effectively, therefore, it should be ensured that teachers understand what spatial thinking is and why it is important to teach (content knowledge); know about effective instructional strategies (pedagogical knowledge); and develop skills to implement those understandings and strategies into their geography classrooms (pedagogical content knowledge). Teachers also possess appropriate dispositions toward incorporating spatial thinking into their daily practices. It is expected that teachers acquire such knowledge and skills and develop dispositions through their preservice education. No knowledge is available, however, about whether the current teacher preparation programs address aspects of spatial thinking in preparing their prospective teachers.

In the next section, I discuss the significance of teacher preparation to foster a generation of spatially-literate students. Previous research on preservice geography teacher preparation is then reviewed. Lastly, I discuss research findings that provide insights into the ways to prepare teachers to be able to teach spatial thinking.

PREPARING TEACHERS TO TEACH SPATIAL THINKING

Significance of Teacher Preparation

It is well recognized that teachers generally teach as they have been taught (Adler 2008; Darling-Hammond 2006b; Petry 1995). Becker said, "the way that teachers teach is a product of their own schooling, training, and experiences as teachers" (Becker 1991, 8). Among a variety of factors that influence a teacher's instructional practices, preservice education seems particularly important because it is the time when prospective teachers are forming their perceptions about, as well as their knowledge of, the subject areas they will be teaching. For example, Doppen (2007) found that explicit experiences of student-centered learning in the teacher preparation program significantly influenced the student teachers' development of favorable dispositions toward student-centered approaches to teaching social studies. Franklin and Molebash (2007) conducted a five-year longitudinal study on 23 elementary teachers' use of technology in the classroom. The purpose was to examine the effect of their experiences in a technologically-enriched social studies methods course they took during their preservice education on their inservice practices related to using technologies. The survey and interview results indicated that explicit integration of technologies into methods courses enhanced beginning teachers' self efficacy and feelings of preparedness to teach with technology and also facilitated the implementation.

The significance of teacher preparation has often been discussed in relation to teacher quality and effectiveness. Darling-Hammond et al. (2005) examined the relationship of teachers' certification status to students' achievement, using a large data set from Houston, Texas during 1995-2002. A series of regression analyses of 4th and 5th grade students' achievement gains on reading and mathematics tests over a six-year period revealed that certified teachers consistently produced higher student achievement gains than did uncertified teachers, even after controlling for teacher experience, degrees, and other student characteristics. The results indicate that teachers' effectiveness is strongly related to the preparation they have received for teaching. There are reviews of research that demonstrate similar results, including Evertson, Hawley, and Zlotnik (1985) and Darling-Hammond (2006c). According to Evertson, Hawley, and Zlotnik (1985)

> [T]he available research suggests that among students who become teachers, those enrolled in formal preservice preparation programs are more likely to be effective than those who do not have such training. Moreover, almost all well planned and executed efforts within teacher preparation programs to teach students specific knowledge or skills seem to succeed, at least in the short run (Evertson, Hawley, and Zlotnik 1985, 8).

Darling-Hammond (2006c) made a similar point but with an emphasis on subject matter knowledge that is typically expected to be better learned through a formal teacher preparation program, saying:

> [R]esearch suggests that the extent and quality of teacher education matter for teachers' effectiveness and add significant value to the general knowledge and skills that teachers with a strong subject matter background bring to the classroom. This may be increasingly true as teachers experience greater demands as a result of the expectation that schools teach a much more diverse group of students for much higher standards (Darling-Hammond 2006c, 20).

Literature in geography education has also emphasized the importance of well-trained teachers to promote teaching and learning practices (Bednarz, Bockenhauer, and Walk 2005; Hermann 1995; Marran 1994). What is generally understood is that preservice teacher education is important especially for implementing new ideas and materials in geography education, such as the National Geography Standards and GIS. In addition, preservice training is often considered the key to success of the implementation of such innovations (Bednarz and Audet 1999). One reason is simply because preservice teachers have more time to acquire the knowledge and skills required to implement the new ideas and innovations into their practice. A fundamental reason would be, as Boehm, Brierley, and Sharma (1994) said, "if all we do is provide inservice training in geography for teachers then we institutionalize the continual need for further inservice teacher training in geography" (Boehm, Brierley, and Sharma 1994, 21). Thus, if spatial thinking is something new that needs to be incorporated in the school curriculum, it is essential that spatial thinking be addressed in the curriculum of teacher preparation programs.

Preservice Geography Teachers

Geography Teacher Preparation

Bednarz and Bednarz (1995) have provided a comprehensive representation of the geography teacher preparation system (Figure 3). It is inclusive because the model considers not only the course work and certification requirements, which are the main components of teacher preparation programs, but it also considers public awareness and education policies important factors as they determine societal demands for preservice geography teacher education. Although the model was proposed more than a decade ago, it is still useful, allowing systematic approaches to almost all problems and issues one can possibly think of regarding geography education and teacher preparation. The present study is, however, concerned more with the components that are directly related to preservice teachers' learning experiences during their preparation as highlighted in the model.

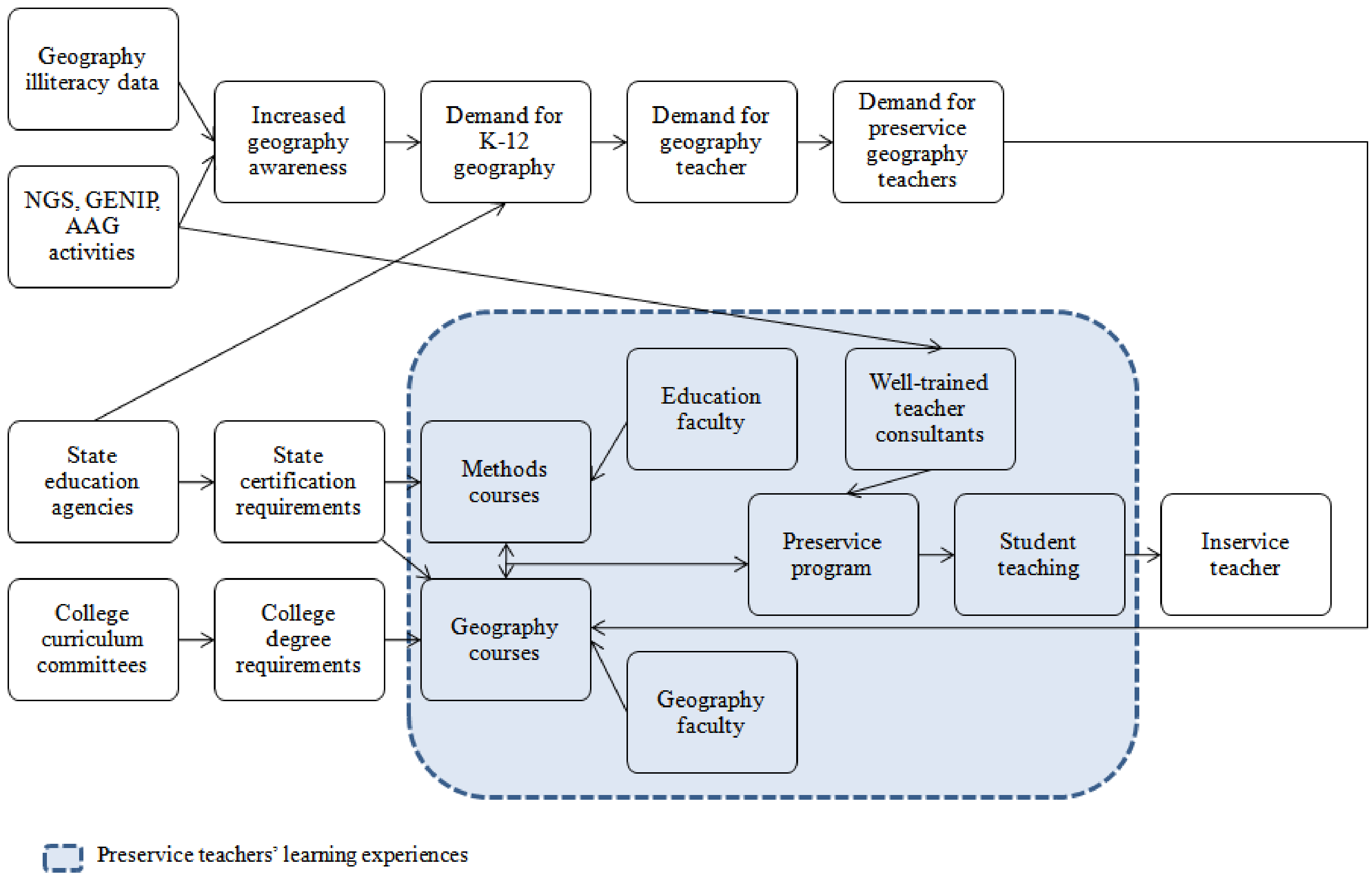


Figure 3. A comprehensive model of the geography teacher preparation system (adapted from Bednarz and Bednarz 1995).

Figure 4 is a simpler model of the geography teacher preparation system where preservice teachers' learning experiences in a typical university-based teacher education program are represented. Despite possible variances across states in their requirements for geography teacher certificates, in general, preservice geography teachers take some geography courses (if any are required and offered) and some education courses; geography courses are taught by faculty in geography whereas education courses, including methods courses, are taught by education faculty. It is expected that preservice teachers learn the subject matter knowledge from geography courses and geography professors and pedagogical knowledge from education courses and professors in education. Once a teacher candidate fulfills such degree requirements and other requirements for teacher certification, he or she is qualified to teach.

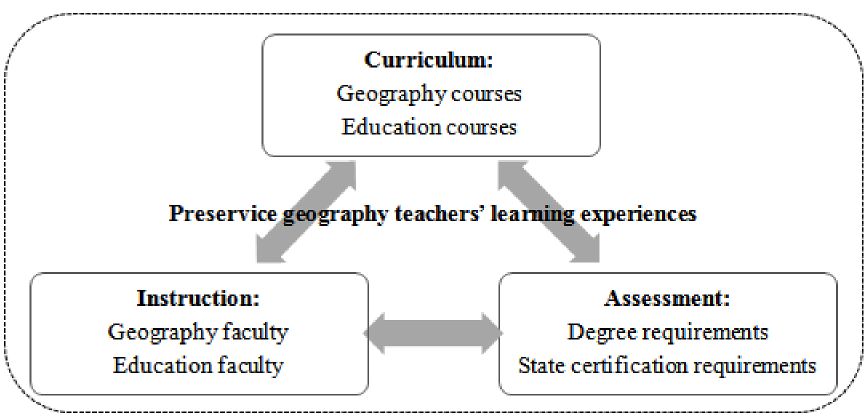


Figure 4. A simple model of the geography teacher preparation system.

Problems arise because the system does not guarantee the development of pedagogical content knowledge, which requires practices of teaching in disciplinary contexts. This would be exacerbated if there is no geography department or a geography professor at institutions of teacher training. As Bednarz and Bednarz (1995) pointed out:

> Those who teach how to teach specific subjects, that is the so-called "methods" professors who prepare students to teach geography (or more commonly social studies), often have little understanding of geography or knowledge of new and innovative ways to teach it (Bednarz and Bednarz 1995, 483).

But, even in teacher-training institutions where there is a department of geography, geography courses are often offered to the general population of students, not necessarily targeted at students preparing to be teachers. Therefore, how to teach geography is not a topic in most of these courses.

A list of actions has been recommended to address such problems (see Bednarz and Bednarz 1995), but one of them seems particularly urgent in incorporating spatial thinking into the teacher preparation system:

> Revise syllabi of courses taken by preservice students to reflect the expectations of the Standards and the K-12 curricula for which these students are being prepared to teach. Re-think the content delivery system, that is, use more active teaching methods and model geography's processes of inquiry (Bednarz and Bednarz 1995, 484).

In geography courses, preservice teachers should be able to learn spatial concepts in geography and spatial perspectives in geography, as emphasized in the Geography Standards. Methods courses must help student teachers recognize the value of spatial thinking across domains and focus more on active practices to incorporate aspects of spatial thinking into the context of subject matter, for example geography, that they will be teaching.

Preservice Geography Teachers' Knowledge, Skills, and Dispositions

Previous research on preservice geography teachers and teacher preparation in geography has mostly focused on the level of preservice teachers' subject knowledge, particularly of place names and location. Herman and Hawkins (1985) examined both elementary and secondary social studies preservice teachers' ability to locate countries on a world map and found serious deficiencies in such knowledge, especially for elementary preservice teachers. Elementary preservice teachers' lack of geographic knowledge in comparison to middle or high school preservice teachers was also reported by Thomas (2001). In addition, May (2005), using an assessment originally designed for 5th graders, evaluated preservice teachers' basic knowledge of global place names and local geography, and skills to apply information from maps, charts, and graphs. The results showed that the geographic knowledge of pre-service teachers remains at a level that is below passing by most public school standards.

Researchers also have examined preservice teachers' self efficacy in teaching specific areas in geography, for example, physical geography, human geography, and geospatial technologies. Rynne and Lambert (1997) surveyed a representative sample of students enrolled in the Post Graduate Certificate in Education program at the University of London Institute of Education in 1994-1995 to examin the level of subject knowledge in geography which those preservice teachers brought to their training as well as their feelings of competence to teach certain topics in geography. The results revealed varying degrees of feelings of these preservice teachers in terms of their competence to teach specific topics. Several topics in physical geography, such as meteorology and climatology were listed as geographic topics least preferred to teach. Skills to use information technologies was another area that about half of the 31 participants expressed concerns about. Akengin's (2008) study also reported that preservice geography teachers had little confidence with their knowledge and skills to use geospatial technologies, like Google Earth, in classrooms.

In general, however, the discussion on teacher preparation in geography is limited and calls for more and better research. As Bednarz, Stoltman, and Lee (2004) pointed out:

> There has been a significant increase in the quality and quantity of school geography in the past 20 years, the result of national efforts to enhance geography education through the national reform movement in education that began in 1984, the Alliance movement underway by 1986, and selective adoption of the *National Geography Standards: Geography for Life* 1994 in state curricula in the last decade. As a result of this development the need for highly qualified geography teachers has grown. Unfortunately, teacher preparation programs (called 'pre-service education') have failed to produce a sufficient supply of adequately trained geography teachers capable of implementing innovations of the past two decades in geography education (Bednarz, Stoltman, and Lee 2004, 177).

Despite growing interests in implementing spatial thinking into geography classrooms, no research evidence is available on preservice geography teachers' knowledge, skills, and dispositions related to teaching spatial thinking. It would be reasonable, however, to assume that many teachers are unlikely to be aware of the nature and importance of spatial thinking, have sufficient skills on how to teach it, and be willing to explicitly integrate it into their teaching practices because spatial thinking has been unappreciated and unrecognized in education until recently (National Research Council 2006). Research evidence that supports or dismisses this postulation is not available, though. Not surprisingly, no research proposed a model for preparing prospective teachers to acquire the knowledge and skills required to teach spatial thinking and develop appropriate dispositional characteristics to incorporate this important skill into their future classrooms. Nevertheless, some insights can be found in the literature on effective teacher education.

Developing Knowledge, Skills, and Dispositions to Teach Spatial Thinking

The Content of Effective Teacher Preparation

Darling-Hammond (2006) pointed that there has been less discussion about: 1) what goes on within the courses and clinical experiences that teacher candidates encounter and 2) how the learning experiences that teacher education programs design for their student teachers cumulatively add up to a set of knowledge, skills, and dispositions that determine what teachers actually do in the classroom. As for the content of teacher preparation, she emphasized that:

> [Teacher education] programs not only to provide teachers access to more knowledge, considered more deeply, but also to help teachers learn how to continually access knowledge and inquire into their work. The skills of classroom inquiry include careful observation and reasoned analysis, as well as dispositions toward an open and searching mind and a sense of responsibility and commitment to children's learning (Darling-Hammond 2006b, 305)

Applying these general recommendations to the context of preparing teachers to teach spatial thinking, teacher preparation programs should offer preservice teachers opportunities to learn knowledge about spatial thinking, skills to infuse this idea into the classroom, as well as positive dispositions toward teaching it and a commitment to students' learning of spatial thinking. That is, teacher preparation programs need to provide their student teachers with learning experiences to help them acquire the pedagogical content knowledge of spatial thinking and to develop dispositions toward implementing it.

The question is how to develop such knowledge, skills, and dispositions. In general, "much is uncertain about the best way to prepare [teacher] candidates to help all students succeed" (Miller 2009, 3); and not surprisingly, no research informs the ways to promote such knowledge and skills through preservice teacher education. As for subject matter knowledge in particular, Gregg (2001) said that even if many teachers took an introductory geography course as a part of their college education or teacher preparation coursework, such classes may not be readily translated into useful knowledge and skills in a classroom. Especially for teaching new or unfamiliar topics such as spatial thinking, "preservice teachers are among the educators most in need of preparing themselves to teach new topics" (Gregg 2001, 61). Ball, Thames, and Phelps (2008) pointed out similar problems in the current teacher preparation coursework, saying:

> Unfortunately, subject matter courses in teacher preparation programs tend to be academic in both the best and worse sense of the word, scholarly and irrelevant, either way remote from classroom teaching … Although there are exceptions, the overwhelming majority of subject matter courses for teachers, and teacher education courses in general, are viewed by teachers, policy makers, and society at large as having little bearing on the day-to-day realities of teaching and little effect on the improvement of teaching and learning (Ball, Thames, and Phelps 2008, 404).

Darling-Hammond (2006c) proposed a list of 'how' teacher preparation should be structured to accomplish these requirements, based on an extensive review of teacher education programs that have been successful in developing such a knowledge base in their teacher candidates (Table 2).

Table 2. Pedagogical cornerstones of teacher preparation effective to develop teachers' knowledge, skills, and dispositions (adapted from Darling-Hammond 2006c).

The *'how'* of teacher education	
Coherence	• Course work sequenced based on a strong theory of learning to teach • Courses designed to intersect with each other • Subject matter learning brought together with content pedagogy through courses
Integration	• Integration between coursework with clinical practice in schools • Extensive clinical work • Intensive supervision • Expert modeling of practice
New relationships with schools	• Efforts to help create school environments for teaching and teacher training through professional developments, lab schools, and school reform networks

A principle for teaching geographic knowledge in teacher preparation suggested by Gregg (2001) is consistent with these general guidelines:

> [T]eacher education programs demonstrate the need for deep, coherent knowledge of central importance to the topic as the basis for lesson planning, teach preservice teachers how to seek out this knowledge, and give them sufficient practice with a few key topics so that they acquire a degree of skill and confidence in doing the research [on the topics to be taught] (Gregg 2001, 67).

It seems, thus, crucial that the curriculum of teacher preparation programs infuse key concepts and ideas about spatial thinking throughout their courses and practices in a more coherent, integrated, as well as explicit manner.

Effective Learning Experiences

An empirical study by Hughes (2005) provides more specific ideas of how teachers develop knowledge, skills, and dispositions toward incorporating something new in their practices. In a case study with four teachers, Hughes (2005) examined how the teachers' learning experiences affected their integration of technology in practice and demonstrated that the degree to which a teacher develops technology-supported pedagogy depends largely on the teacher's interpretation of the value of the technology for supporting classroom instruction and learning. She wrote:

> Teachers within a discipline make pedagogical decisions about instruction and learning based on what they believe to be the purpose(s) for teaching the content, what knowledge they believe students should be developing (noting what has been taught in previous and subsequent grade levels), what discipline-based teaching materials are available, and what representations or activities have been successfully used in their past teaching (Hughes 2005, 279).

Applying this to the context of teaching spatial thinking, therefore, it is unlikely that teachers would invest time and energy in finding effective ways to use it in their classrooms unless they understood and believed in the value of spatial thinking. Without adequate knowledge about spatial thinking and spatial perspectives in geography, teachers would not make efforts to determine when, where, and how aspects of spatial thinking could be incorporated into teaching practices.

As Bednarz and Bednarz asserted (2008):

> If we can explain how spatial thinking supports geography learning more clearly and powerfully, we are confident that teachers will decide to incorporate it more quickly, and the rate of progress will increase … We still need to explore explicitly ways to better explain and communicate the power of spatial thinking to learning geography and other social studies

and linking that to effective instructional strategies (Bednarz and Bednarz 2008, 264)

Another finding by Hughes (2005) was that learning experiences which focused on teaching technology within the general educative examples were effective to demonstrate technology's general educative value and this, in turn, inspired teachers to explore the possibilities for the technology in their own classrooms. When addressing spatial thinking in preservice teacher education, therefore, it would be a good strategy to introduce several examples demonstrating general educative value of spatial thinking so that preservice teachers become inspired to explore the potential of incorporating spatial thinking into their classrooms.

It was also observed in the study that the more content-specific the example, the more likely the teacher will see value and learn it while the farther the example is from the teacher's content area, the lower the likelihood that the teacher would spend time developing other possibilities for the technology. In addition, learning experiences that focused solely on technology with no connections to education or their content areas did not lead to innovative technology-supported pedagogy. These findings confirm that learning to teach spatial thinking should occur in the context of a specific domain. That is, preservice geography and social studies teachers should be provided in their training with examples of teaching spatial thinking in geographic contexts. It would be beneficial to see how spatial thinking is related to teaching geographic knowledge and skills through concrete classroom examples.

Meanwhile, Ormrod and Cole (1996) provide some insights regarding the format of delivery. Although research indicates that teachers' knowledge, skills, and dispositions develop slowly (Bednarz and Bednarz 2008; Darling-Hammond 2006c), their study reported that a two-week summer institute, which explicitly focused on key concepts and principles of geography and specific strategies for teaching some of these concepts and principles, was effective in enhancing participants' pedagogical content knowledge. Teachers can certainly not acquire in-depth knowledge of geography and spatial thinking in two weeks, and ideally pedagogical content knowledge for teaching spatial thinking skills must be embedded throughout the teacher preparation coursework. Nonetheless, summer institute or workshop-type learning experiences would serve at least two important functions: 1) to provide teachers with tools and guided practice to teach spatial thinking through geography and 2) to generate awareness, understanding, and enthusiasm for pursuing further effort to implement spatial thinking into their future classrooms. It is important, however, that summer institute or workshop-type learning experiences ensure that teachers have opportunities to practice the ideas and skills they are introduced to. As Binko (1989) pointed out, teacher education workshops often focus only on awareness and understanding of new ideas and skills. The level of skill and confidence that teachers need for an effective implementation of the new ideas to their own classrooms, however, cannot be achieved unless they had sufficient opportunities to practice related skills. Therefore, teacher education workshops need to be designed in a way that teachers can practice implementing new ideas and skills into a classroom context in an environment where they can receive immediate feedback on their progress from teacher educator, peer teachers, or mentors.

Summary

Numerous studies support a claim that preservice teacher education is the key to success in implementing educational innovations. If spatial thinking is something new but important to be incorporated in the school curriculum, it is essential that spatial thinking be addressed in the curriculum of teacher preparation programs. In order for geography teachers to be able to teach spatial thinking, they must learn about it during their preservice education.

The current geography teacher preparation system does not support the development of pedagogical content knowledge for teaching spatial thinking. Almost no opportunities are provided to preservice teachers to explicitly practice incorporating spatial thinking into the subject matter, for example geography. It seems critical that in geography courses, preservice teachers should be able to learn spatial concepts in geography and spatial perspectives in geography explicitly. It would be ideal if such learning could occur in relation to the Geography Standards. Methods courses must help student teachers recognize the value of spatial thinking across domains and focus more on active practices to incorporate aspects of spatial thinking into the context of subject matter that they will be teaching.

No research proposed a model for preparing prospective teachers to acquire knowledge and skills required to teach spatial thinking and develop appropriate dispositional characteristics toward incorporating this important skill into their future classrooms. The literature on effective teacher education indicates that the curriculum of teacher preparation programs should infuse key concepts and ideas about spatial thinking throughout their courses and practices in a more coherent, integrated, as well as explicit manner.

CHAPTER III

METHODOLOGY

A one-day, approximately four hours long, workshop "Teaching Spatial Thinking with Geography," targeted to preservice teachers was developed as the intervention of this study in order to understand effective ways of promoting preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking. The primary purpose of the workshop was to provide participants with an explicit opportunity to learn about spatial thinking and to practice skills required to incorporate spatial thinking into their future practices.

Three assessments were used to examine changes in participants' knowledge, skills, and dispositions, before and after the workshop: a spatial concepts test, a teaching spatial thinking disposition survey, and participant-produced mini-lesson plans. Individual interviews were conducted for a deeper understanding of participants' learning experiences during the workshop. This chapter describes the research design, methods, and procedures involved in the intervention and the assessment tools developed and used.

RESEARCH DESIGN

A three-session workshop, titled "Teaching Spatial Thinking with Geography" was developed by the researcher and delivered to a group of preservice teachers enrolled in the courses taught in the College of Education and Human Development at Texas

A&M University. The educational effect of the workshop was examined by comparing pre- and post-assessments measuring participants' knowledge, skills, and dispositions toward teaching spatial thinking.

The research design and procedures of this study are summarized in Figure 5. A mixed-method design was used to collect and analyze data. Specifically, the study employed a concurrent triangulation strategy where the data were collected and analyzed in both quantitative and qualitative ways simultaneously within a single study (Creswell and Plano-Clark 2007). Using both quantitative and qualitative methods help confirm, cross-validate, and corroborate findings by offsetting the weaknesses inherent within one method with the strengths of the other method.

Quantitative data were collected during pre- and post-assessment phases: scores on the spatial concepts test; responses to the teaching spatial thinking disposition survey; and the spatiality of participant-produced lesson objectives and assessments. A taxonomy of spatial thinking developed by Jo and Bednarz (2009) was used to evaluate and quantify the spatiality of lesson objectives and assessments. Interview transcripts and descriptions of teaching and learning procedures in participant-produced lesson plans produced qualitative data. Results from both quantitative and qualitative analyses were integrated during the interpretation phase of the study. The focus was on the extent to which the findings from the quantitative and qualitative data corroborate each other.

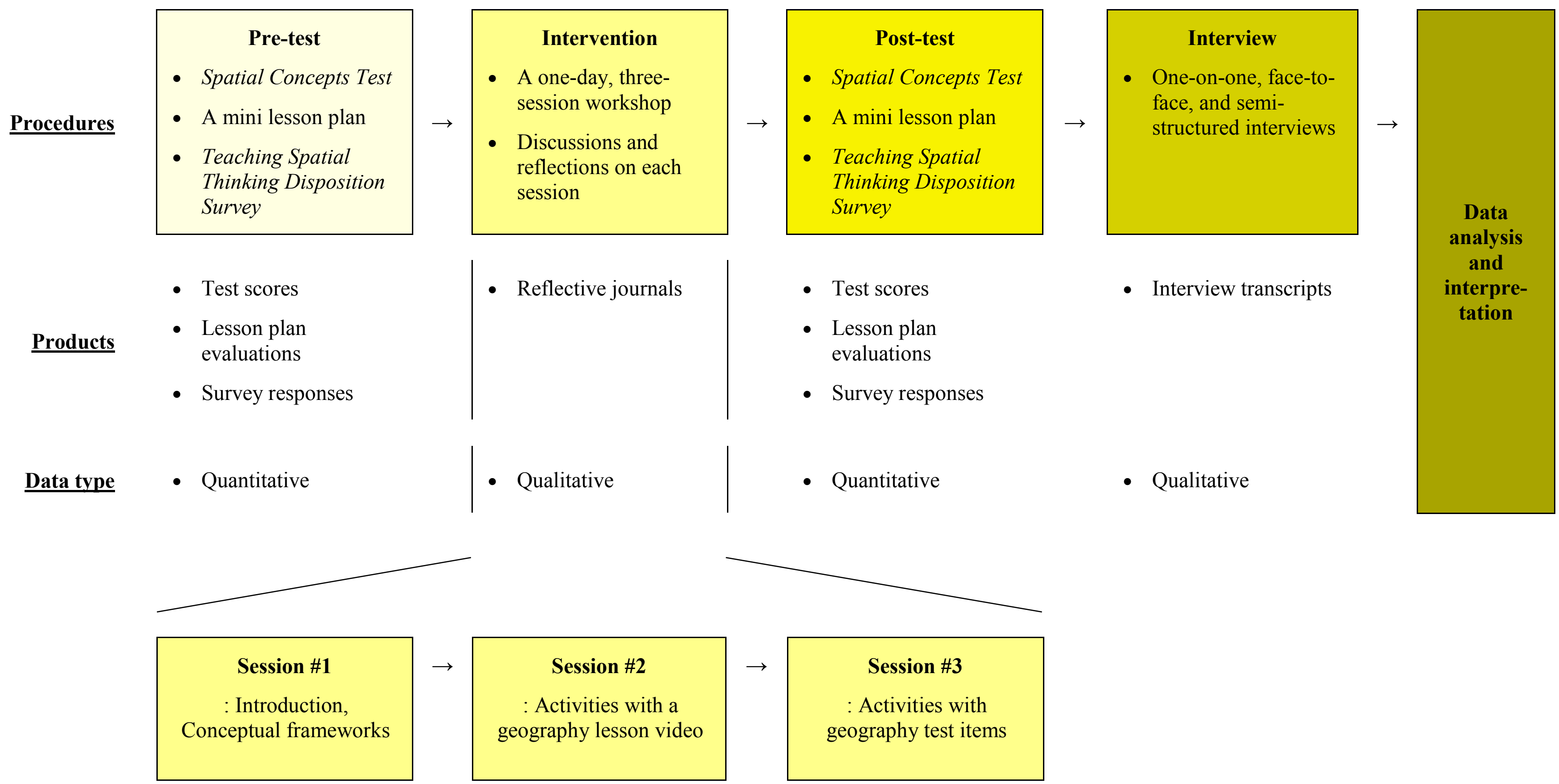


Figure 5. Research design.

PARTICIPANTS

Twenty four undergraduate students participated in this study. Most participants (21 out of 24) were recruited from social studies methods courses taught in the College of Education and Human Development at Texas A&M University in the fall 2010. No specific program or course targeted for preservice geography teachers is currently offered. Therefore, this group of students best fit the purpose of this study because they will be teaching social studies, of which geography is a component. The other three participants were recruited by the participants themselves through informal routes. For example, they encouraged friends who were seeking teacher certificates to participate in the study.

Twenty one participants were female, and three were male. The participants were all seeking elementary or middle school teacher certification, majoring in Interdisciplinary Studies with an emphasis on elementary education – Early Childhood through 6th grade (13 out of 23), middle school language arts and social studies for4th through 8th grade (6 out of 23), bilingual education – Early Childhood through 4th grade (3 out of 23). There was one geography major and one sociology major. All but one student were seniors; and one was a junior. The average number of courses in geography taken by participants was 1.6, mostly in introductory human geography, world regional geography, or introductory physical geography. The average number of courses taken in Interdisciplinary Studies was 6.6 including a social studies methods course. Study participation was strictly voluntary but a $50 compensation was paid to each participant.

TEACHING SPATIAL THINKING WITH GEOGRAPHY WORKSHOP

A three-session workshop targeted to preservice teachers was developed by the researcher and used as the intervention of the study. Each session lasted 50-60 minutes; the entire workshop, except for the time for pre- and post-assessment, took about four hours including a break and lunch time. The workshop was offered three times to adapt to the participants' schedule as much as possible, and held on three Saturdays during the fall 2010 semester – October 23rd, November 7th, and November 21st.

The primary objective of the workshop was to enhance preservice teachers' awareness and understanding of spatial thinking and have them practice incorporating the three components of spatial thinking into teaching practices. To achieve these goals, a series of learning experiences was devised. Shulman's (1986, 1987) notion of pedagogical content knowledge formed a theoretical basis on which the learning experiences were designed. Pedagogical content knowledge is a particular form of content knowledge, "which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (Shulman 1986, 9). In order for a teacher to be effective, it is necessary that the teacher have pedagogical understanding of the subject matter. Likewise, in order to be able to teach geography in a way that enhances spatial thinking, the teacher should know about the subject matter of geography, spatial thinking, as well as effective ways to represent spatial concepts and ideas in a comprehensive way to their students.

With this rationale, the first session of the workshop was designed to provide preservice teachers with basic yet fundamental information about spatial thinking, such as its definition, three component parts, and its significance in people's everyday lives, at work, and in academics. The session also explicitly discussed important spatial concepts that teachers and students should know. The second and third sessions were designed to address pedagogical content knowledge related to teaching spatial thinking in geography. Although no empirical research exists on the pedagogical content knowledge needed to teach spatial thinking, it would be reasonable to assume that a geography lesson where the teacher implements the three components of spatial thinking – concepts of space, using tools of representation, reasoning processes – into a classroom context would be a good model to illustrate pedagogical content knowledge of teaching spatial thinking through geography. In the second session of the workshop, the participants watched an exemplary geography lesson and analyzed it from a spatial perspective. The intention was to help participants visualize the 'teachability' (Shulman 1986, 9) of spatial thinking in their future classrooms by watching and analyzing a real lesson. Another presumption was that a teacher's ability to design spatial thinking questions is an essential part of his or her pedagogical content knowledge to teach spatial thinking. The last session of the workshop was designed, therefore, to develop participants' questioning skills to ensure that spatial thinking would be addressed in their future assessment practices.

In summary, the workshop was developed in a way to assist the prospective teachers in making meaningful connections between their newly acquired knowledge of spatial thinking and a variety of teaching practices. Details of the learning experiences for each session are described in the next three sections.

Session #1

In the first session, participants were provided with background about the importance of developing spatial thinking skills in education and the potential of geography as a school subject to do this. A taxonomy of spatial thinking developed by Jo and Bednarz (2009) (Figure 6) was introduced as a framework to learn the three components of spatial thinking and to review important spatial concepts. The information was presented primarily in the form of a Power Point presentation (Appendix A) by the researcher. A short discussion about possible applications of the taxonomy to teaching practices followed at the conclusion of the session. The outline of the presentation was:

- What is thinking and a thinking skill?
- What is spatial thinking?
- Spatial thinking and geography
- Questions related to teaching spatial thinking with geography
- A taxonomy of spatial thinking as a tool to teach spatial thinking
- Three components of spatial thinking: concepts of space, using tools of representation, and processes of reasoning
- Application of the taxonomy to a variety of teaching practices

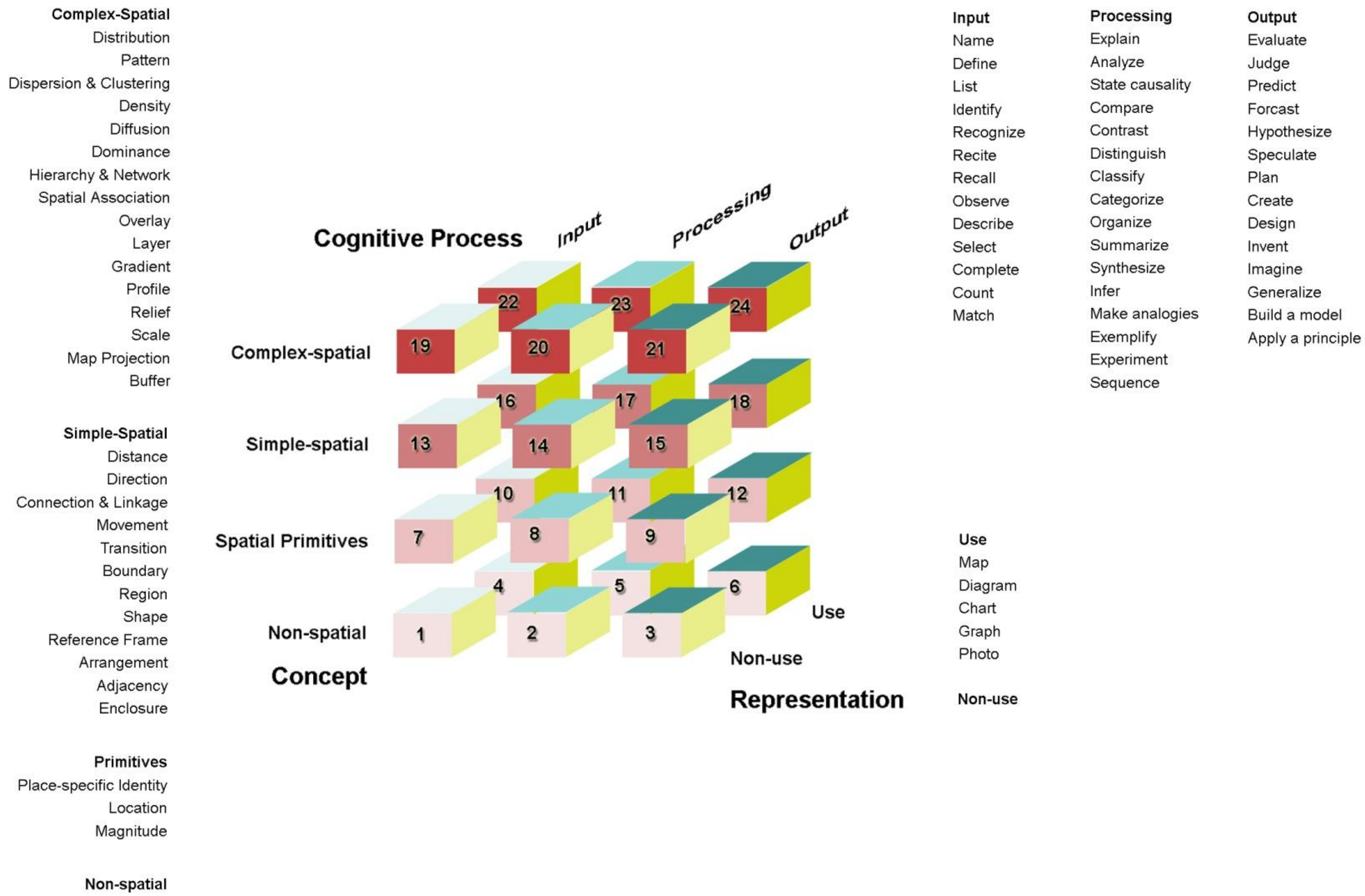


Figure 6. Taxonomy of spatial thinking (Jo and Bednarz 2009).

Session #2

As mentioned, the second and third sessions were designed to provide participants with an opportunity to apply their knowledge about spatial thinking acquired from the first session to real-world contexts. In the second session, participants watched a video of an exemplary geography lesson and analyzed the lesson against the three components of spatial thinking: concepts of space, using tools of representation, and reasoning processes. A worksheet (Appendix B) was provided to guide the analysis; and the taxonomy of spatial thinking introduced in the first session was used as a tool. The guiding questions for the lesson analysis and following discussion included:

- What kinds of concepts are discussed throughout the lesson?
- What kinds of tools of representation are used for students' learning?
- What kinds of cognitive processes do the students practice during the class?

The focus was on how well the video lesson addressed aspects of spatial thinking and how it could be improved, so that students could practice spatial thinking more explicitly.

Session #3

The last session was designed to provide participants with an opportunity to analyze, evaluate, and design questions from a spatial perspective. Six questions sampled from the exit level social studies Texas Assessment of Knowledge and Skills (TAKS) test (administered in April 2009) were used as the prompts. A worksheet (Appendix C) was provided to help the analysis procedures. Participants shared their ideas and opinions on how the test items could be revised to stimulate students' practice of spatial thinking at the end of the session.

After each session, participants were asked to write a reflective journal entry about their learning experiences. Prompt questions for the reflective journal included:

- What are the three most important things I took away from the session?
- What is the new knowledge learned about (teaching) spatial thinking?
- What kinds of skills were developed to teach spatial thinking in my future classrooms?
- Are there any changes in my attitude, willingness, or dispositions toward teaching spatial thinking?

MEASURES OF KNOWLEDGE, SKILLS, AND DISPOSITIONS

Spatial Concepts Test

Test Description

Concepts of space are the building blocks of spatial thinking. They make spatial thinking a distinctive way of thinking by using space as a framework for understanding, structuring, and solving problems (National Research Council 2006). Acquiring knowledge of spatial concepts is critical in the development of one's spatial thinking skills. Considering the importance of spatial concepts in spatial thinking, it seems necessary that a teacher possess sufficient knowledge and understanding of spatial concepts to promote students' spatial thinking skills. One of the purposes of this study is to examine the educational effects of a workshop on preservice teachers' knowledge of spatial concepts. However, there are no tests developed to assess one's understanding of spatial concepts. Thus, a new test was developed for this study.

A spatial concepts test (Appendix D) was developed particularly to assess preservice teachers' understanding of some of the important spatial concepts. The development of this test followed several steps: (1) identification of the test domain; (2) specification of the concepts and levels of knowledge of the concepts to be tested; (3) construction of the initial pool of items; (4) content validation and review of the item quality; (5) pilot testing; and (6) refinement and revision of the test.

The test domain was defined as knowledge of spatial concepts, guided by a taxonomy of spatial thinking by Jo and Bednarz (2009), originally devised based on Golledge's work (1995, 2002). Fourteen spatial concepts selected from the taxonomy constituted the initial pool of test items. These concepts vary in terms of the level of complexity: one spatial primitive – location; four simple-spatial concepts – reference frame, boundary, distance, and region; and nine complex-spatial concepts – scale, pattern, density, map projection, topographic profile, diffusion, overlay, buffer, and spatial association. The types of conceptual knowledge required in the test were both conceptual knowledge and procedural. Following Tennyson and Cocchiarella's definition, conceptual knowledge of a concept was defined as "formation of attributes (i.e., a prototype) and appropriate connections to other concepts (i.e., a schema)" and procedural knowledge was defined as "the classification skills of generalizing to and discriminating between newly encountered instances of associated concepts" (Tennyson and Cocchiarella 1986, 44).

Ten items out of 14 asked participants to select the concept that best represented the difference between two given images or maps, where the difference was in the target concept's critical attribute (Figure 7). For example, one map of the pair (item #4) represents a long distance between two locations whereas the other map shows a short distance. The other features remain constant. In order to answer this question correctly, one must have conceptual knowledge of 'distance' and understand that the concept involves two locations separated from each other, and able to be described as 'long,' 'short,' 'far,' etc. A person also has to possess procedural knowledge of the concept to answer the question correctly. For example, one might choose 'location' as the answer instead of 'distance' because there were different locations marked on the maps. However, the attributes represented on the maps, such as 'long' and 'short,' are not critical attributes of the concept 'location,' therefore it cannot be the best answer to the question. The required knowledge here is procedural knowledge to discriminate the concept 'distance' from other associated concepts such as 'location.'

[4-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay

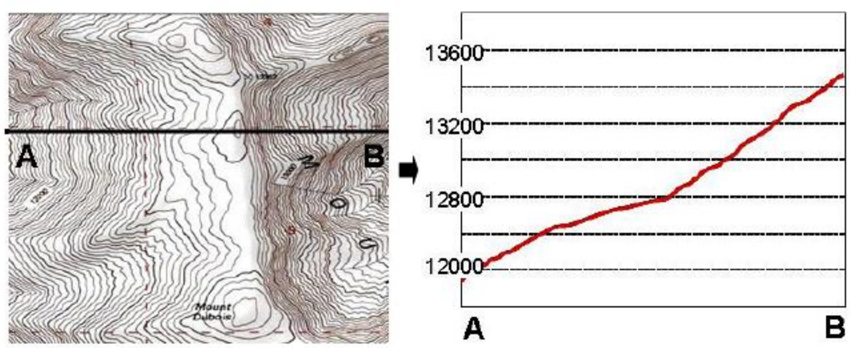
[4-2] Provide AT LEAST ONE rationale for your selection.

____

____

[10-1] Select ONE concept (circle on it) that BEST describes the PROCESS (or SEQUENCE).

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay



[10-2] Provide AT LEAST ONE rationale for your selection.

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Figure 7. Example items of the spatial concepts test.

The other four items asked participants to choose the concept that best described the sequence of given images or maps (Figure 7). The four concepts asked were: (topographic) profile, diffusion, overlay, and buffer. The given images or maps were basically a visual representation of the process involved with a concept. The focus was more on conceptual knowledge rather than procedural knowledge, considering the high abstractness of these concepts. Meanwhile, in answering each of the test items participants were required to provide at least one written rationale or explanation to support their choice. The purpose was to make sure that the answer was not just a random choice.

The initial test was reviewed by two geography experts (Ph. D. candidates in geography) to ensure the content validity and quality of the items. The process was judgmental rather than statistical. The reviewers looked through the test carefully and evaluated each item in terms of whether the images or maps in each item clearly represented a critical attribute of the targeted concept; and whether each item was relevant to the purpose of the test. After individual review of the test, a disscussion followed to make a decision whether to keep an item as it was, to revise, or to eliminate it from the test. The reviewers agreed that all items were relevant to the test domain. As for the quality of items, eight items were considered good as they were; six items were judged to need minor revisions; and no item was discarded.

A pilot test was conducted with 10 preservice geography and social studies teachers and to ensure the effectiveness and usefulness of the items to achieve the test objective. A rigorous statistical item analysis, including item difficulty and item discrimination, could not be done with this small number of participants. However, a minimum level of item difficulty analysis was conducted which increased the effectiveness of the test; the proportion of examinees that had the correct response to each item on the pre-test was calculated. Two items that had zero percent correct responses (items for the concepts 'spatial association' and 'buffer') were eliminated to increase score variance. The final version of the test consisted of 12 items on spatial concepts: location, reference frame, boundary, distance, region, scale, pattern, density, map projection, topographic profile, diffusion, and overlay.

Test Setting and Administration

Participants were given 12 minutes to complete the spatial concepts test. Before each test, participants reviewed two practice items (one for difference questions; the other for sequence questions) with the researcher to ensure they understood the nature of the test and how to answer the questions. Two versions of the test were developed, one for the pre- and one for the post-tests. They were composed of questions covering the same spatial concepts but having slightly different images or maps.

Data Scoring and Analysis

Performance on the test was measured by the total number of questions answered correctly. The mean scores on the pre- and post-tests were analyzed using a paired sample t-test. An alpha level of .05 was used to determine whether there was significant difference between the two tests. If a significant score increase occurred in the post-test, an effect size (Cohen's *d*) was calculated to measure the practical significance of the increase.

A further analysis was conducted, based on the percentage of correct responses to each item before and after the workshop. The purpose was to figure out the concepts most of the participants already knew well; the concepts most of them did not know well; and the concepts which the workshop had the greatest effect in enhancing understanding. Some misunderstandings that the participants had were identified as well. Participant interview data were concurrently compared and integrated into this analysis to ensure that the findings from the quantitative and qualitative data support each other.

Mini-Lesson Plan

Task Description

Participants' skills to teach spatial thinking were measured using lesson plans they developed before and after the workshop. A teacher's skills to teach spatial thinking would be best measured if the researcher could observe them teaching students in a real classroom. However, such a setting was impossible because all participants were at least one semester from their student teaching, which would provide them with full access to a classroom teaching opportunity. For this study, therefore, it was assumed that a teacher's lesson plan was a valid indicator of the teacher's skills to teach, reflecting skills to formulate appropriate learning objectives, to design and employ effective classroom activities, and to ask appropriate spatial questions.

Instruction in the purposes and main components of a lesson plan were provided by the researcher. A copy of a high school level world geography textbook chapter about settlement patterns and ways of life in Canada was given as the material to work with.

Participants read through the text individually and had a group discussion to share information about the material. Then approximately 30 to 40 minutes was given to design an individual mini lesson plan. A lesson-plan template (Appendix E) and guidelines for designing a lesson plan were provided to keep the format of the lesson plans consistent. Participants were asked to include in their lesson plans: 1) three lesson objectives, including concepts they thought important for students to learn; 2) step-by-step lesson procedures, such as students' and the teacher activities; and 3) three assessment questions or tasks.

Data Coding and Analysis

The spatiality of a lesson plan was evaluated based on the three components of spatial thinking addressed. A taxonomy of spatial thinking developed by Jo and Bednarz (2009) was used as a tool for this evaluation. Each of the objectives and assessment items was coded according to the taxonomy by: 1) classifying the concepts that the objective (or assessment item) required students to know (i.e., non-spatial, spatial primitives, simple-spatial, complex-spatial concepts); 2) determining the nature of the tools of representation that the objective (or assessment item) asked students to use (i.e., non-use, use); and 3) classifying the cognitive processes that each objective (or assessment item) expected to address (i.e., input, processing, output level). Examples of coding for lesson objectives and assessment items are illustrated in Table 3.

Table 3. Example coding of lesson objectives and assessment items.

Example	Concept	Using tools of representation	Processes of reasoning	Taxonomy Cell
To explain why they believe Canada is a plural society	Non-spatial	Non-use	Processing	2
To name and describe each of Canada's regions	Simple-spatial	Non-use	Input	13
To explain patterns of settlement due to climate conditions through class discussion and evaluation of maps	Complex-spatial	Use	Processing	23

Participants' pre- and post-lesson plans were compared in terms of: 1) the degree to which each individual component of spatial thinking was addressed in the objectives (or assessment items); and 2) the degree to which the objectives (or assessment items) integrated the three components of spatial thinking. Whether an objective (or assessment item) integrates the three components was measured by its location in the 24 cells of the taxonomy (Figure 6). The objectives (or assessment items) categorized into nine cells, 10, 11, 12, 16, 17, 18, 22, 23, and 24, were viewed as integrating all three components of spatial thinking to some extent. Among these, those classified in Cells 10, 11, and 16 are at the simplest level of spatial thinking, involving low level spatial concepts and cognitive processes. An objective (or assessment item) to identify a location on a map would be an example. Objectives (or assessment items) falling into Cells 12, 17, and 22 are at a higher level of spatial thinking than Cells 10, 11, and 16. An example is a question that requires students to compare two regions using a map. Objectives (or assessment items) categorized into Cells 18, 23, and 24 are viewed as representing spatial thinking at its highest complexity and abstractness, requiring knowledge about complex-spatial concepts, use of representations, and the highest level of cognitive processes. A lesson objective to make generalizations about a pattern featured on a map is an example of spatial thinking at this level.

As for the teaching and learning procedure of a lesson plan, only the difference from pre- to post-lesson plan was analyzed. The reason for not coding the whole lesson was because of the varying lengths and degree of details of each response. Coding participants' descriptions of teaching and learning procedures sentence by sentence would cause a bias in the result in that it would reflect the spatiality of longer responses more than that of relatively shorter ones. Taking only the difference between pre- and post-lesson plans was considered a way to minimize such bias. The focus of the analysis was the degree to which each of the three components of spatial thinking was incorporated in participants' post-lesson plans in comparison to pre-lesson plans.

Participants were asked to explain their rationales for revising the lesson plans during the interview phase. The purpose was to ensure that the revision was based on their increased understanding of spatial thinking.

Teaching Spatial Thinking Disposition Survey

Survey Description

In this study, dispositions toward teaching spatial thinking is defined as a teacher's awareness of spatial thinking as an important thinking skill, beliefs that spatial thinking can and should be taught, and inclinations to incorporate spatial thinking into the class in an explicit manner. There is no measure developed to assess teachers' dispositions associated with teaching spatial thinking. A new instrument – teaching spatial thinking disposition survey (Appendix F) – was developed for this study. The initial questionnaire included 48 items. The criticality of each item to measure a teacher's awareness, beliefs, and inclinations regarding spatial thinking were evaluated by two geography experts (Ph.D. candidates in geography). Sixteen items out of 48 were eliminated because the statement was either vague or considered not very critical to measure the construct. The final questionnaire consisted of 32 statements to be rated on a scale from one to four (i.e., 1: strongly disagree; 4: strongly agree).

Each of the 32 statements is associated with a teacher's beliefs about student learning of thinking skills, awareness of spatial thinking and its relationship to geography, or inclinations toward teaching spatial concepts and skills and to use tools of representation. Items #1 through #8 ask whether one believes in the teachability of thinking skills (e.g., I believe that thinking skills can be taught); prioritizes developing students' thinking skills (e.g., My highest priority goal will be developing students' thinking skills); and is willing to stimulate students' thinking in the classroom (e.g., I will almost always ask students to provide explanations and reasons to support their answers). Newmann's (1991; 1992) characterizations of 'thoughtful classrooms' provided ideas to construct these items.

Items #9 through #16, on the other hand, ask how a person perceives geography and geography learning (e.g., I believe that geography has much to do with asking questions and solving problems) and whether he/she is aware of spatial thinking as one of the geographic ways of thinking (e.g., I believe that spatial thinking is an essential part of learning geography). The National Geography Standards (Geography Education Standards Project 1994), which emphasizes spatial perspectives in geography, as well as ecological perspectives, provided the justification for this important characteristic of a teacher who would value spatial perspectives in teaching and learning geography.

A definition of spatial thinking as "a constructive amalgam of concepts of space, tools of representation, and processes of reasoning" by the National Research Council

(National Research Council 2006) provided insights to construct the rest of the survey items. Items #17 through #23 involve characteristics of a teacher who understands spatial thinking as a powerful skill in a variety of contexts (e.g., I believe that spatial thinking is integral to everyday life) and as an important thinking skill that needs to be nurtured (e.g., I believe that spatial thinking skills should be learned by everyone). Items #24 through #32 characterize a teacher who understands the importance of teaching spatial concepts explicitly (e.g., I will explicitly teach concepts of spatial pattern, scale, density, and spatial diffusion) and having students use and create a variety of spatial representations to develop their spatial thinking skills (e.g., I believe that using and creating tools of representations, such as maps, diagrams, and graphs are essential for spatial thinking).

Among these 32 items, five of them were counter-statements (items #5, 9, 10, 19, and 27) that represent either the unawareness of spatial thinking or disagreement on the importance of thinking skills in learning geography. The purposes of including these items were first to ensure that participants paid enough attention to the survey and second to filter out possible contradictions in a person's responses. For example, it would be considered contradictory if one strongly agrees to the idea that geography has much to do with asking questions and solving problems (item #11), but believes that geography has much to do with rote memorization of isolated facts (item #10). It would be more reasonable that the person agrees to one statement but disagrees to the other.

Data Scoring and Analysis

Possible points for each item ranges from one (strongly disagree) to four (strongly agree), and a possible disposition score one can obtain ranges from 32 (1 x 32) to 128 (4 x 32). Five items (#5, 9, 10, 19, and 27) were scored with a reverse-scale (i.e., strongly disagree: 4; strongly agree:1) because a strong agreement on these items indicates little likelihood to implement spatial thinking into teaching practices.

The mean scores on the pre- and post-survey were analyzed using a paired sample t-test. An alpha level of .05 was used to determine whether there was significant difference between pre- and post-survey scores. If a significant score increase occurred in the post-test, an effect size (Cohen's *d*) was calculated to measure the practical significance of the increase.

Interview

Questionnaire Descriptions

One-on-one, face-to-face, and semi-structured interviews were conducted with 23 participants (the researcher failed to meet one participant). The primary purpose was to better understand the effects of the workshop on their conceptualization of spatial thinking, knowledge and skills to incorporate spatial thinking into their practices, and feelings and opinions about the overall learning experiences in the workshop. Interviews were arranged according to each participant's schedule but completed within one week of the intervention. Each interview took about an hour.

The interview questionnaire included 13 questions. Three questions were about the participant's background, such as academic major, grade level, and course experiences both in geography and in education. Four questions were related to their experiences in the workshop including overall evaluations, most liked session, benefits of the workshop for future practices, and suggestions. There were two questions about how the workshop affected their conceptualization of spatial thinking and geography. On the other hand, three questions served as a way to check participants' responses to the other measures. During the interview, each participant reviewed their answers to the spatial concepts test, responses to the teaching spatial thinking disposition survey, and mini lesson plans they produced and asked to provide elaborations, clarifications, and verifications of the responses. Participants were also asked their opinions on the relationship between knowledge, skills, and dispositions toward teaching spatial thinking.

Data Coding and Analysis

All interviews were audio-recorded with participants' permission and then transcribed. The transcripts were analyzed using the constant comparative method. In this method the categories of units are likely to emerge as data coding proceeds, and the constant comparison of a unit with the other units leads the development of categories (Lincoln and Guba 1985).

Participants' responses to the interview were processed in the following steps: 1) unitizing; 2) categorizing; and 3) recognizing patterns of emerging categories. The interview transcripts were unitized, breaking the data into pieces of information so that each of them is "the smallest piece of information about something that can stand by itself" (Lincoln and Guba 1985, 345). Each unit was then entered onto an index card, and each index card was coded with the information of interview date, respondent identification number, and the corresponding page in the transcript. The categorization process was initially done by the questions on the interview questionnaire. The categories were next reviewed to ensure that they are "internally as homogeneous as possible and externally as heterogeneous as possible" (Lincoln and Guba 1985, 349). Each category was then located in relation to each of the research question for the comparison with the quantitative data. Table 4 summarizes the four assessment tools used for this study.

Table 4. Summary of the instruments.

Instrument	Spatial Concepts Test	Mini Lesson Plan	Teaching Spatial Thinking Disposition Survey	Interview Questionnaire*
Purpose	Measuring knowledge of spatial concepts	Assessing skills to teach spatial thinking	Measuring dispositions toward teaching spatial thinking	Deeper understanding participants' learning experiences
Components	12 items on each of the following spatial concepts: • Location • Reference frame • Boundary • Distance • Region • Scale • Pattern • Density • Map projection • Topographic profile • Diffusion • Overlay	• Lesson objectives • Teaching and learning procedures* • Assessment	• Beliefs on teaching thinking skills in general (Items 1-8) • Perspectives on geography and geographic learning (Items 9-16) • Awareness of spatial thinking in general (Items 17-23) • Inclination to teach spatial thinking (Items 24-32)	• Educational background (Questions 1-3) • Effect of and opinions on the workshop (Questions 4, 5, 6, 7, 11, 12, and 13) • Member checking on the other assessments (Questions 8, 9, and 10)
Administration	• 12 minutes • Pre and Post	• 40 minutes • Pre and Post	• 10 minutes • Pre and Post	• 1 hour • Post only

*Qualitative data

CHAPTER IV

RESULTS AND ANALYSIS

This chapter describes the outcome of the study in relation to the four research questions:

1. Does explicit instruction in spatial thinking enhance preservice teachers' knowledge required to teach spatial thinking (content knowledge)?
2. Does explicit instruction in spatial thinking enhance preservice teachers' skills to teach spatial thinking (pedagogical content knowledge)?
3. Does explicit instruction in spatial thinking enhance preservice teachers' dispositions toward teaching spatial thinking in their future classrooms?
4. What is the relationship among preservice teachers' knowledge, skills, and dispositions related to teaching spatial thinking?

The discussion is organized in the same order as the research questions. In each of the four sections, quantitative results are presented first. Qualitative outcomes are then reported, focusing on whether, and to what extent, they support the quantitative results.

RESEARCH QUESTION 1: KNOWLEDGE ACQUISITION

As described in Chapter III, both quantitative and qualitative methods were used to examine the research questions. The first research question was initially examined using statistical analyses (i.e., mean, paired *t*-test, Cohen's *d*) of participants' scores on the spatial concepts test. Participant narratives on the test and in the interview were then analyzed to examine whether, and to what extent, the qualitative outcomes support the statistical results.

Concepts Test Score

The spatial concepts test consisted of 12 items on spatial concepts: location, reference frame, boundary, distance, region, scale, pattern, density, map projection, topographic profile, diffusion, and overlay. The first nine items out of 12 asked participants to select the concept that best represented the difference between two given images or maps, where the difference was in the target concept's critical attribute. The other three items asked participants to choose the concept that best described the sequence of given images or maps. With 12 items, the possible score ranges from zero to 12. Table 5 and Figure 8 show the score distribution of the 24 participants on both pre- and post-tests. For the pre-test, the scores ranged between one and eight. The average was six, and the median was seven. Fifty percent (12 out of 24) answered either six or seven questions correctly. No one scored above eight.

Table 5. Score distributions on the spatial concepts test.

		Score												Total
		1	2	3	4	5	6	7	8	9	10	11	12	
Pre-test (Mean=6.00) (Median=7.00) (SD=2.00)	Frequency	1	1	2	3	4	9	3	1	0	0	0	0	24
	Percent	4.17	4.17	8.33	12.50	16.67	37.50	12.50	4.17	0.00	0.00	0.00	0.00	100.00
Post-test (Mean=9.33) (Median=9.50) (SD=1.74)	Frequency	0	0	0	0	0	1	4	2	5	6	3	3	24
	Percent	0.00	0.00	0.00	0.00	0.00	4.17	16.67	8.33	20.83	25.00	12.50	12.50	100.00

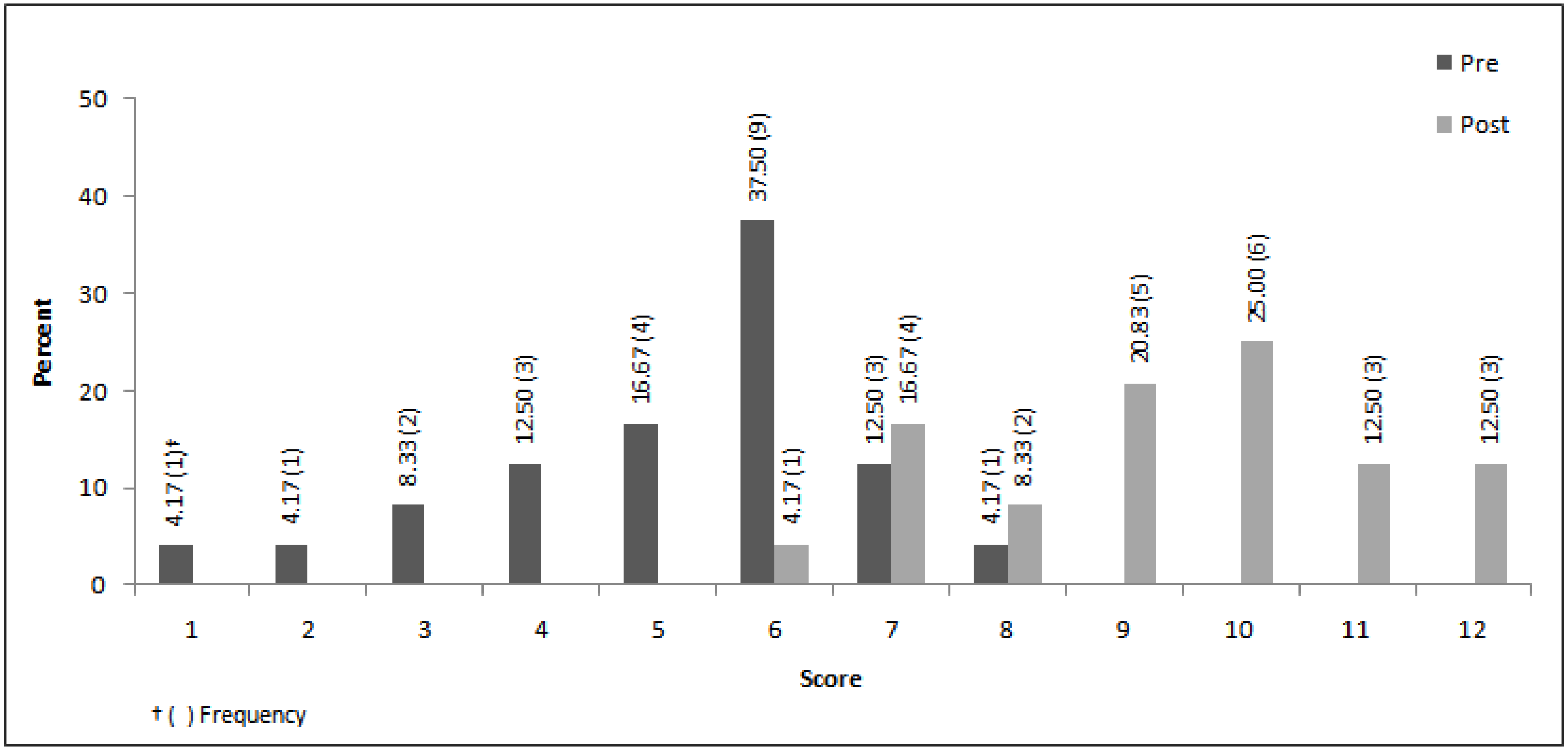


Figure 8. Score distributions on the spatial concepts test.

Overall, participants performed better on the post-test. The post-test scores ranged from six to 12, and the average was 9.33. There was no participant who scored below six while about 46 percent of participants (45.83 percent, 11 out of 24) received either nine or ten points. The mean difference between pre- and post-test (3.33) was statistically significant (95% CI 2.57 to 4.10; $t = 9.02$, $p < .001$). The effect size for this mean increase ($d = 2.45$) showed that the result was also practically significant. In other words, there was positive educational effect of the workshop on participants' knowledge of spatial concepts. The criterion for educational effect is $d = .50$ (Wolf 1986).

Participants' performance on pre- and post-tests was analyzed also by the specific concept tested (Table 6 and Figure 9). Almost all participants answered questions on 'location' and 'distance' correctly in both the pre- and post-tests. The item showing the lowest percentage correct was about the concept of 'overlay' (8.33 percent, 2 out of 24) in the pre-test while the lowest percentages correct in the post-test were found on the concepts 'boundary' (50.00 percent, 12 out of 24) and 'pattern' (41.67 percent, 10 out of 24). On the pre-test, slightly over half of the participants got the right answers for 'region,' 'diffusion,' 'scale,' and 'map projection' whereas only about one third of participants chose correct answers to 'reference frame' (33 percent, 8 out of 24), 'profile' (33 percent, 8 out of 24), 'density' (29.17 percent, 7 out of 24), and 'pattern' (25.00 percent, 6 out of 24). The percentage correct was over 50 percent for all items in the post-test except for the item of 'pattern' (41.67 percent, 10 out of 24).

Table 6. Number and percentage correct by concept (concepts ordered from high to low frequency).

		Concept											
		Location	Distance	Region	Diffusion	Scale	Map projection	Boundary	Reference frame	Profile	Density	Pattern	Overlay
Pre-test	Frequency	23	23	16	16	13	12	10	8	8	7	6	2
	Percent	95.83	95.83	66.67	66.67	54.17	50.00	41.67	33.33	33.33	29.17	25.00	8.33

		Concept											
		Location	Distance	Diffusion	Scale	Map projection	Region	Profile	Overlay	Density	Reference frame	Boundary	Pattern
Post-test	Frequency	24	23	22	22	20	19	19	19	17	17	12	10
	Percent	100.00	95.83	91.67	91.67	83.33	79.17	79.17	79.17	70.83	70.83	50.00	41.67

		Concept											
		Overlay	Profile	Density	Reference frame	Scale	Map projection	Diffusion	Pattern	Region	Boundary	Location	Distance
Change (post minus pre)	Frequency	17	11	10	9	9	8	6	4	3	2	1	0
	Percent	70.83	45.83	41.67	37.50	37.50	33.33	25.00	16.67	12.50	8.33	4.17	0.00

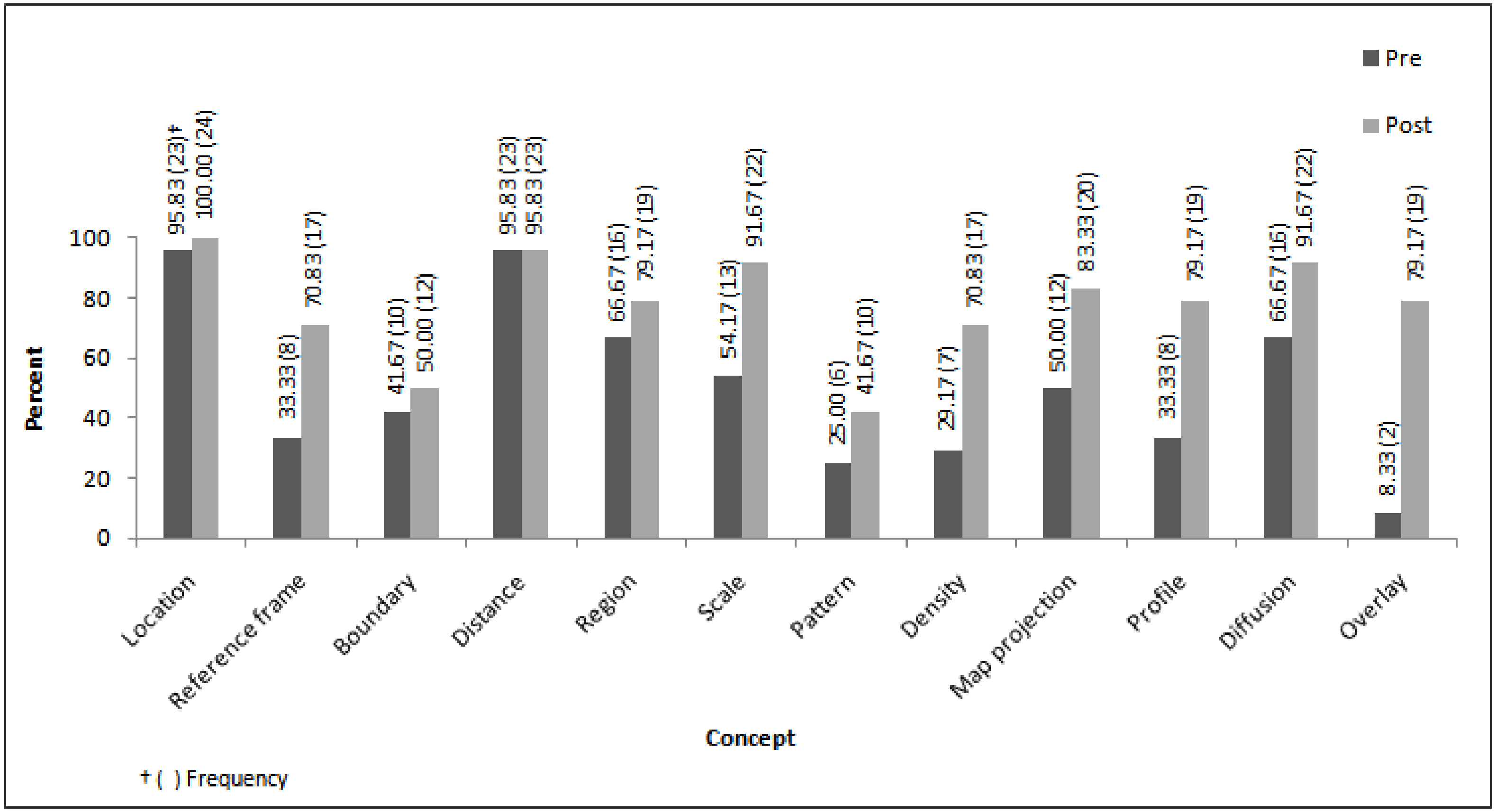


Figure 9. Number and percentage correct by concept.

Changes in the percentages correct for each item between pre- and post-tests were also calculated. As shown in Table 6, the increase was most notable for the concept ‘overlay’ (70.83 percent, from 2 to 19) followed by ‘profile’ (45.83 percent, from 8 to 19), and ‘density’ (41.67 percent, from 7 to 17).

Participant Narratives

Participants’ narratives were analyzed by unitizing, categorizing, and identifying patterns of the categories. Besides confirming the quantitative results, three themes emerged as a result of the qualitative analysis of the data: 1) prior knowledge about spatial concepts; 2) misunderstandings of spatial concepts and corrections of them; and 3) deepened understanding of spatial concepts.

Prior Knowledge about Spatial Concepts

Participants’ explanations in the test and narratives about the test obtained through an interview confirmed the quantitative results, in that most preservice teachers had fairly accurate understandings of ‘location’ and ‘distance’ prior to the workshop. Table 7 includes several examples of participants’ explanations of these concepts with indicators of their knowledge about the concepts italicized. All examples for ‘location’ demonstrate that they understand that the concept of location involves the question of where something is; and that a location is often represented as a point on a map. The examples for ‘distance’ show their understanding that the concept, distance, involves a spatial relationship between two points; and that its critical attributes can be described as ‘long,’ ‘short,’ ‘far,’ etc.

Table 7. Participant explanation of the concepts – location and distance (example).

Location	Distance
• Left-handed image has the selected *location (A) in bottom right** and right-handed image has selected *location (B) in upper right*.	• Images show a line associated with distance *between two points*.*
• If there was a line suggesting a route, I would have chosen distance. I think the *markers* suggest locations.	• The two pictures compare the distance *between New York to Philadelphia and New York to Washington, D.C.*
• Both images show the locations of two *specific points*.	• Two arrows suggest location but the yellow *line (route)* suggest distance *between*.
• *Markers* A and B are pointing to different locations on the same map.	• These two photos show *a route – same starting point, two different destinations.* It demonstrates different distances to two different places.
• *Point* A is identified at a different location than *point* B on the same map.	• I chose distance because the distance *between the first two cities is much shorter* than the second two cities.
• The difference between the two pictures is *the location of the marker*.	• Washington D.C. is *farther away* than Philadelphia from New York.
* Indicators of one's conceptual knowledge about 'location' italicized	* Indicators of one's conceptual knowledge about 'distance' italicized

On the other hand, many of the participants had little knowledge of the concept, 'reference frame' as suggested in the pre-test results. In their reflections on the test during the interview, participants often said, "I didn't know what reference frame meant" and "I had never really heard of the term, reference frame." However, there were a few who possessed accurate understandings. For example, one participant wrote, "The longitude and latitude lines help a map reader to gain a frame of reference for measuring a specific location." Responses such as "By adding latitude and longitude lines, you are providing people with a frame of reference" also represent a good understanding of the concept.

Many participants expressed difficulty in providing a reasonable explanation on some of the complex-spatial concepts, such as 'pattern' and 'profile,' supporting the low average score for these concepts on the pre-test. Nevertheless, some participants showed basic understanding of these concepts as well as about other complex-spatial concepts, including 'scale,' 'map projection,' and 'diffusion.' For example, one participant said (indicators of one's conceptual knowledge about the concept italicized):

> One of the maps looks more *zoomed-in* than the other. The *map scale* is different because one picture displays a more *close-up view*.

In this case, the participant discerned that the maps in the question represent almost the same area, around the Great Lakes, but are of different map scales. She used expressions such as 'zoomed-in' and 'close-up' to describe the map in a larger scale. The response did not inform whether she knew a definition of map scale (e.g., the ratio between a distance on a map and the corresponding distance on Earth) and could explain differences between a large-scale map and a small-scale map in other map properties (e.g., greater coverage but less detail in a small-scale map). However, the response indicates that she had a reasonable sense of the concept of scale and how to express its critical attributes, which are the relative sizes on the map in comparison to the sizes in the real world.

An example of participants' basic knowledge about map projection is:

> [The two maps] both show the same thing [a world map], they are just *projected differently*.

It can be inferred that the participant understood the nature of maps, a two-dimensional representation of the three-dimensional Earth. It is not clear, however, that the participant knew what exactly a map projection is and how different map projections affect a variety of features on the map.

The following two examples are about the concept of pattern:

> The map on the right has *parallel and perpendicular streets [patterns]* and the map on the left does not.

> These maps show different *spatial patterns* in city development.

The first quote shows that the participant knew the fact that pattern is a matter of arrangement. In the second example, the participant even made an inference that the different street patterns might be a result of the different processes of city development. Both participants demonstrated their knowledge of the meaning and appropriate usages of the concept.

An example explanation of the concept of profile is:

> If the first map was made 3D and *cut across where the black line is*, then the second picture would be the resulting picture.

As the participant described, a topographic profile is a cross-cut image of a three-dimensional object or feature (e.g. mountains). The purpose is often to see the general topography or outline along a vertical plane passing through the feature. It is particularly useful to figure out elevation changes and differences along the reference line. Although it is not clear whether the participant also understood such functions, the response represents a basic understanding of the concept.

The last example is about the concept of diffusion, where the participant was using one of the best expressions to describe a diffusion process, 'spread out.'

> First map increases as the idea of technology is *spread out among surrounding places*.

As described above, some concepts were well understood by most of the participants whereas the level of knowledge about other concepts was relatively low.

Correcting Misunderstandings of Spatial Concepts

Analysis of participants' narratives also allowed detection of misunderstandings about spatial concepts that the participants possessed. As shown in Table 8, most of the misunderstandings could be attributed to the fact that they had little opportunity to explicitly learn such concepts and so relied on their ordinary and naïve, rather than domain-specific and professional, vocabulary to understand the concepts. For example, one participant chose 'map projection' for the question of 'reference frame' because she thought 'map projection' was a way to project lines, which are latitude and longitude lines in this case, on a map. This indicates that she knew neither 'reference frame' nor 'map projection' exactly. Another participant chose 'scale' over 'reference frame' because she thought that the term 'scale' would best represent latitude and longitude lines because they provide a measurement of Earth space. This is a case illustrating that the participant did not have an accurate understanding of both concepts and interpreted the terms based on her ordinary and naïve sense of vocabulary. One participant chose 'profile' over 'reference frame.' He actually recognized the process represented in the question correctly, saying "One is a top view while the other is a side view." Nevertheless, he selected the wrong answer because he had no idea of the concept 'profile' and interpreted 'reference frame' as a point of view. A similar example comes from the case of a participant who chose 'diffusion' over 'scale' because he reasoned that the zoomed-in map was a result of 'diffusion' of the map itself.

In most cases the problems participants encountered were from insufficient knowledge and learning experiences rather than from their deficiencies of ability to understand the situations in the questions. Therefore, once they learned about these concepts in an explicit manner from the workshop, with definitions, prototypes, and best examples, most participants were able to revise such misunderstandings (Table 8).

Table 8. Correction of misunderstandings after the workshop (example).

Misunderstandings featured in the pre-test		Corrections on the post-test
I think the map projection is different because picture #1 projects the lines, whereas #2 does not.* **'Map projection' was chosen over 'reference frame.'*	→	The picture on the right has coordinates as a frame of reference.* **The correct answer 'reference frame' was chosen.*
[T]here is a scale by which to locate positions on the left map.* **'Scale' was chosen over 'reference frame.'*	→	Right map has longitude and latitude lines, frame of reference.* **The correct answer 'reference frame' was chosen.*
One is a top view while the other is a side view.* **'Reference frame' was chosen over 'profile.'*	→	This is a slice of what the landscape looks like from the top (left image) and the side (right image).* **The correct answer 'profile' was chosen.*
I chose diffusion because the 2nd image looks zoomed-in.* **'Diffusion' was chosen over 'scale.'*	→	The 2nd image is zoomed out.* **The correct answer 'scale' was chosen.*

Deepening Conceptual Knowledge

Besides evidences of correcting misunderstandings (changes from incorrect to correct understanding), participants' explanations in the post-test demonstrated their deepened understanding of spatial concepts (changes from shallow to deeper understanding). As shown in the previous section, the participants' knowledge about most of the complex-spatial concepts, if any, was at a very basic level. That is, although they picked the correct answers, their explanations did not represent a deeper understanding of the concepts, including the ability to provide a detailed definition, describe the functions of the concept, or give domain-specific usages of the concepts. Some of the post-test responses showed improvements in the level of such basic knowledge (Table 9). Also, for those who chose the correct answers on the pre-test but were not sure about their choices thus couldn't provide a clear explanation, the workshop provide opportunities to clarify the knowledge (unclear to clear understanding regardless of the level of understanding).

Summary

Participants' scores on the spatial concepts test revealed that the workshop had positive educational effect on the development of preservice teachers' knowledge required to teach spatial thinking. Qualitative data also confirmed that the workshop contributed to the overall enhancements in knowledge of spatial concepts. The next section reports the findings regarding Research Question 2, in which the educational effect of the workshop on preservice teachers' skills development was examined.

Table 9. Deepened understanding of concepts (example).

Conceptions in the pre-test		Conceptions in the post-test
You take Hispanic population. And then urban areas to create urban, Hispanic areas.* **Overlaying process was implied but not explicitly mentioned.*	→	Each image from left to right adds on a new layer to the map.* **The process of adding layers was explicitly described.*
I chose reference frame because of the points of reference (degrees and Tropic of Cancer).* **Only the meaning of the concept is described.*	→	There is a reference frame that allows you to describe location more accurately.* **Not only the meaning of the concept but also the function of it is explained.*
Not sure.* **The respondent chose a correct answer but was not sure about it.*	→	The difference is that you can only reference from what you see in the first one; then in the second you can reference by the coordinates.* **The respondent was more confident with her choice.*
I have seen this in a class but cannot remember what it is called. I think it is the depth of the land – where the mountains, where the land slopes down, etc. I see that overall, it is mostly decreasing.* **The description was accurate, but the respondent wasn't able to recall the concept.*	→	The profile of the land is shown in the graph of the lined part in the map. **The respondent was able to recall and use the concept properly.*

RESEARCH QUESTION 2: SKILLS DEVELOPMENT

Participants' skills to teach spatial thinking were measured through an analysis of lesson plans they developed during the pre- and post-tests conducted before and after the workshop. A taxonomy of spatial thinking proposed by Jo and Bednarz (2009) (Figure 6) was used as a tool to evaluate the spatiality of the lesson plans. The spatiality of lesson objectives and student assessment items was quantified and analyzed using descriptive statistics, such as frequency and percentage. Teaching and learning procedures of the lesson plans were analyzed qualitatively by unitizing and categorizing the data. Participants' narratives about their lesson plans obtained through an interview were also examined. These qualitative outcomes were then compared to the quantitative results.

Spatiality of Participant-Produced Lesson Objectives

Each of the lesson objectives was coded according to the taxonomy by: 1) classifying the concepts that the objective required students to know (i.e., non-spatial, spatial primitives, simple-spatial, complex-spatial concepts); 2) determining the nature of the tools of representation that the objective asked students to use (i.e., non-use, use); and 3) classifying the cognitive processes that each objective expected to address (i.e., input-level, processing-level, output level). A total of 71 objectives were analyzed.

Figure 10 compares pre- and post-lesson objectives in terms of the level of concepts featured. Commonly in both pre- and post-lesson objectives, simple-spatial concepts were featured most (53.52 percent, 38 out of 71; 49.30 percent, 35 out of 71, respectively), and non-spatial concepts were least addressed (4.23 percent, 3 out of 71;

and 2.82 percent, 2 out of 71, respectively). The number of lesson objectives that require understanding of complex-spatial concepts, such as 'pattern' and 'distribution,' increased in the post-lesson plans, from 15.49 percent (11 out of 71) to 26.76 percent (19 out of 71).

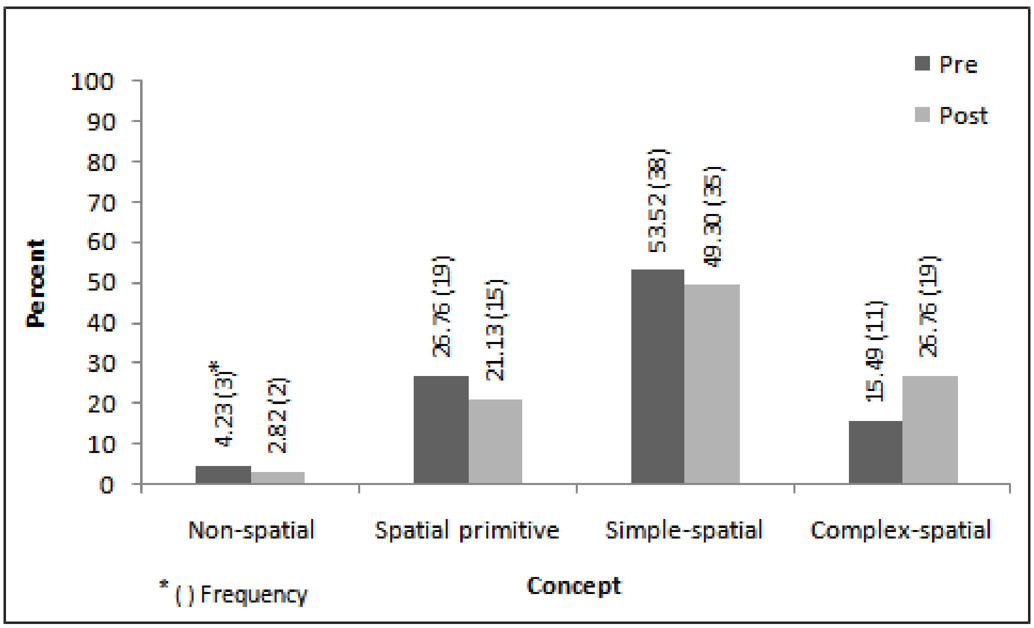


Figure 10. Spatiality of lesson objectives, by concept type.

The majority of both pre- and post-lesson objectives had nothing to do with using or creating spatial representations (77.46 percent, 55 out of 71; and 69.01 percent, 49 out of 71, respectively) (Figure 11). However, participants designed relatively more objectives related to using tools of representation in their post-lesson plans (30.99 percent, 22 out of 71) than in the pre-lesson plans (22.54 percent, 16 out of 71).

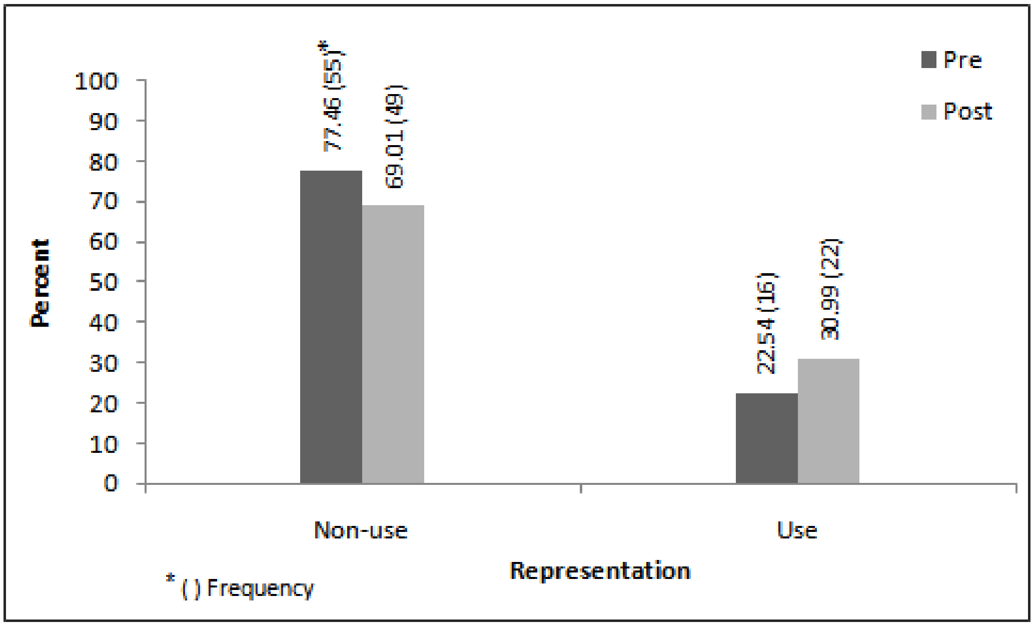


Figure 11. Spatiality of lesson objectives, by tools of representation.

Pre-test results showed that nearly half of the objectives out of 71 were associated with the cognitive processes of processing-level; about 41 percent (29 out of 71) were related to input-level thinking; and only about 10 percent (7 out of 71) were at output-level (Figure 12). In the post-test, on the other hand, the number of objectives addressing input-level thinking decreased to 25.35 percent (18 out of 71) while those demanding processing- and output-level cognition increased to 57.75 percent (41 out of 71) and 16.90 percent (12 out of 71), respectively.

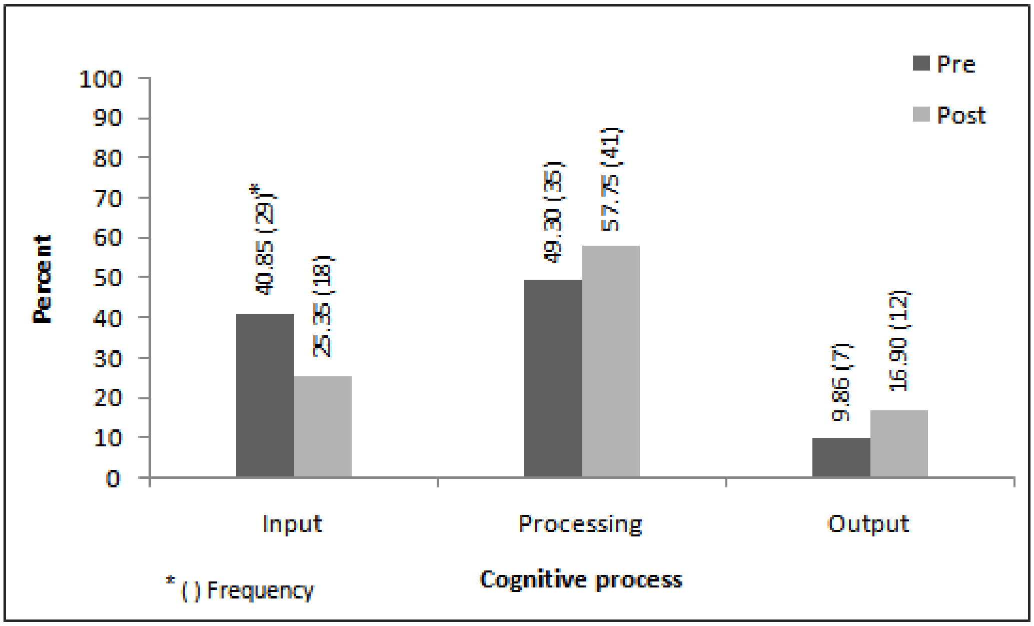


Figure 12. Spatiality of lesson objectives, by cognitive process.

As described in Chapter III, whether a lesson objective integrates the three components was determined by its location in the twenty-four cells of the taxonomy (Figure 6). Lesson objectives categorized into nine cells, 10, 11, 12, 16, 17, 18, 22, 23, and 24, were viewed as integrating all three components of spatial thinking. Among these, objectives classified in cells 10, 11, and 16 are at the simplest level of spatial thinking, involving low level spatial concepts and cognitive processes. Objectives falling into cells 12, 17, and 22 are at a higher level of spatial thinking than cells 10, 11, and 16, and those categorized into cells 18, 23, and 24 were considered representing spatial thinking at its highest complexity and abstractness, engaging students with knowledge about complex-spatial concepts, use of representations, and the highest level of cognitive processes.

In the pre-test, about 79 percent (56 out of 71) lacked integration of the three components (Figure 13). In the 15 objectives, in which all three components were incorporated, objectives at the simplest level spatial thinking were 9.86 percent (7 out of 71). Slightly less than six percent (4 out of 71) involved the highest level spatial thinking. In the post-test, percent decreases were observed for both not-integrated (78.87 to 70.42 percent, 56 to 50 out of 71) and the simplest level spatial thinking (9.86 to 7.04 percent, 7 to 5 out of 71) categories. On the other hand, the number of objectives addressing relatively higher level spatial thinking increased (cells 12, 17, and 22 category: 5.63 to 8.45 percent, 4 to 6 out of 71; cells 18, 23, and 24 category: 5.63 to 14.08 percent, 4 to 10 out of 71).

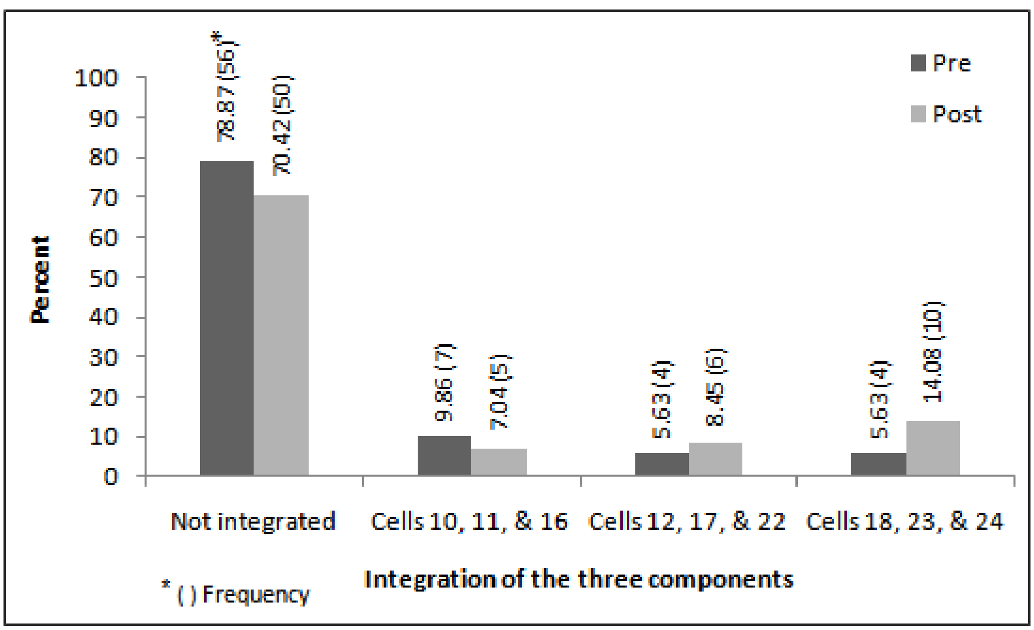


Figure 13. Spatiality of lesson objectives, by integration of the three components.

Overall, the spatiality of participant-produced lesson objectives increased after the workshop. The next section compares the spatiality of participant-produced assessment items between before and after the intervention.

Spatiality of Participant-Produced Assessment Items

The items developed by participants to assess students' learning in the lesson plans were coded in the same way as the objectives for the lesson plans discussed in the previous section. Using the taxonomy of spatial thinking, each of the assessment items was evaluated in terms of the concept that the assessment item required students to know (i.e., non-spatial, spatial primitives, simple-spatial, complex-spatial concepts), whether the item asked students to use or create a spatial representation (i.e., non-use, use), and the cognitive processes that the item required of the student to answer (i.e., input-level, processing-level, output-level). A total of 71 assessment items for pre-lesson plans and 74 items for post-lesson plans were analyzed.

The pre- and post-test results show a pattern that simple-spatial concept assessment items appeared most frequently (in the pre-test 43.66 percent, 31 out of 71; in the post-test 50.00 percent, 37 out of 74), followed by those about spatial primitives (in the pre-test 33.80 percent, 24 out of 71; in the post-test 21.62 percent, 16 out of 74) (Figure 14). As for the percentage changes from pre- to post-tests, assessment items focused on non-spatial concepts and spatial primitives decreased (non-spatial concepts: from 11.27 to 8.11 percent, from 8 out of 71 to 6 out of 74; spatial primitives: from 33.80 to 21.62 percent, from 24 out of 71 to 16 out of 74). Meanwhile, those requiring simple-spatial and complex-spatial concepts increased (simple-spatial concepts: from 43.66 to 50.00 percent, from 31 out of 71 to 37 out of 74; complex-spatial concepts: from 11.27 to 20.27 percent, from 8 out of 71 to 15 out of 74) increased.

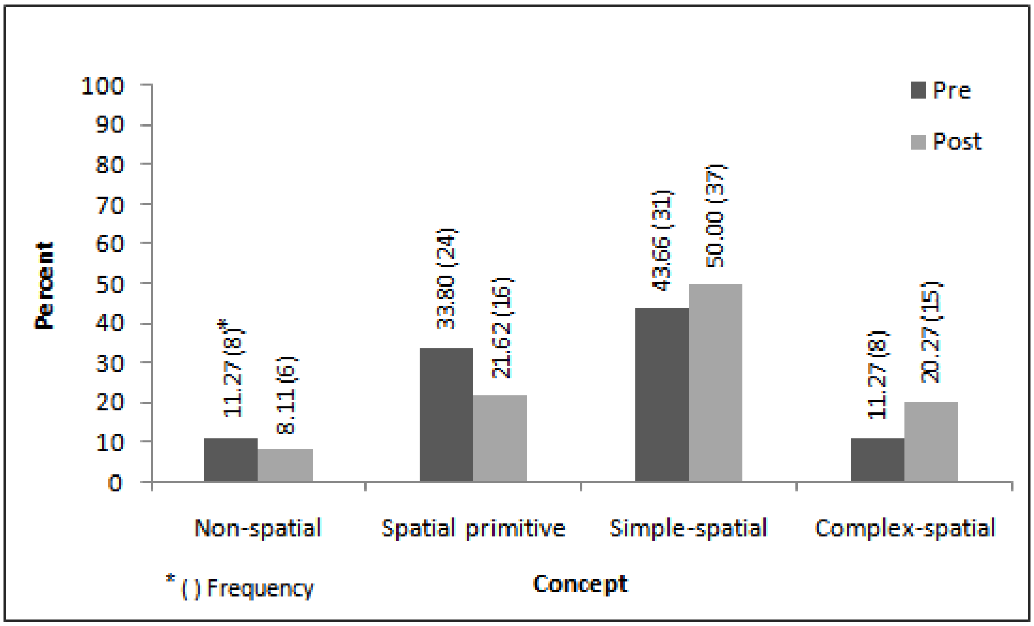


Figure 14. Spatiality of student assessment, by concept type.

The degree to which spatial representations were used in the assessment items is illustrated in Figure 15. Only 38.03 percent of pre-assessment items required students to use representations. The percentage of assessment items involving the use of representations showed about a 10 percent increase in the post-lesson plans (from 38.03 to 48.65 percent, from 27 out of 71 to 36 out of 74).

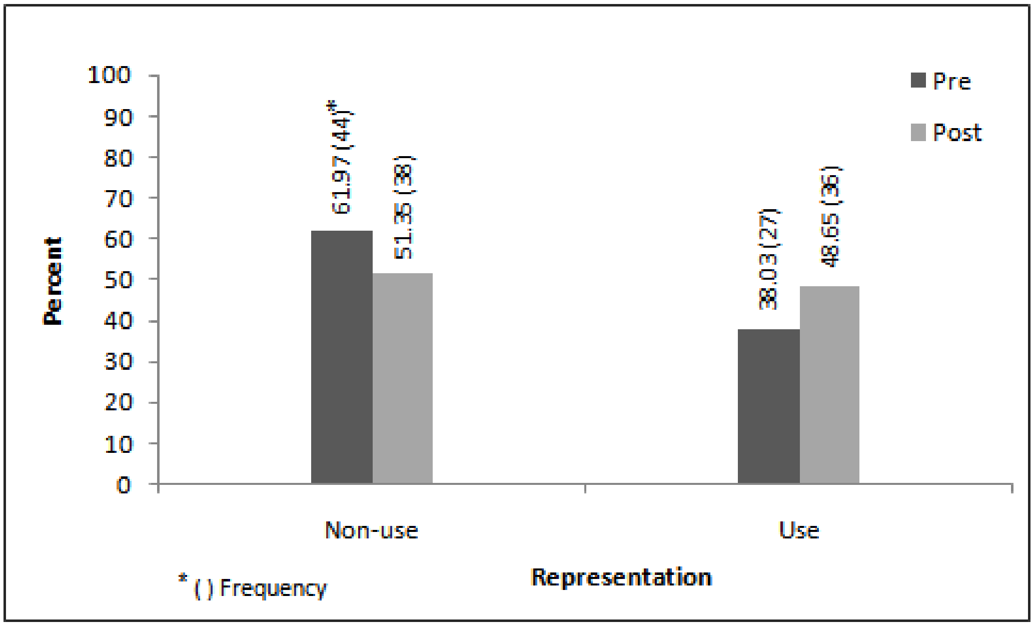


Figure 15. Spatiality of student assessment, by tools of representation.

As presented in Figure 16, pre-assessment items included a similar number of questions that required input-level (38.03 percent, 27 out of 71) or processing-level (39.44 percent, 28 out of 71) cognitive processes. Output-level thinking was featured least (22.54 percent, 16 out of 71). In the post-assessment items, however, the pattern was slightly different. There were more questions requiring output-level (33.78 percent, 25 out of 74) than input-level cognitive processes (31.08 percent, 23 out of 74). Post-assessment items exhibited the same pattern in that processing-level thinking was required the most (35.14 percent, 26 out of 74).

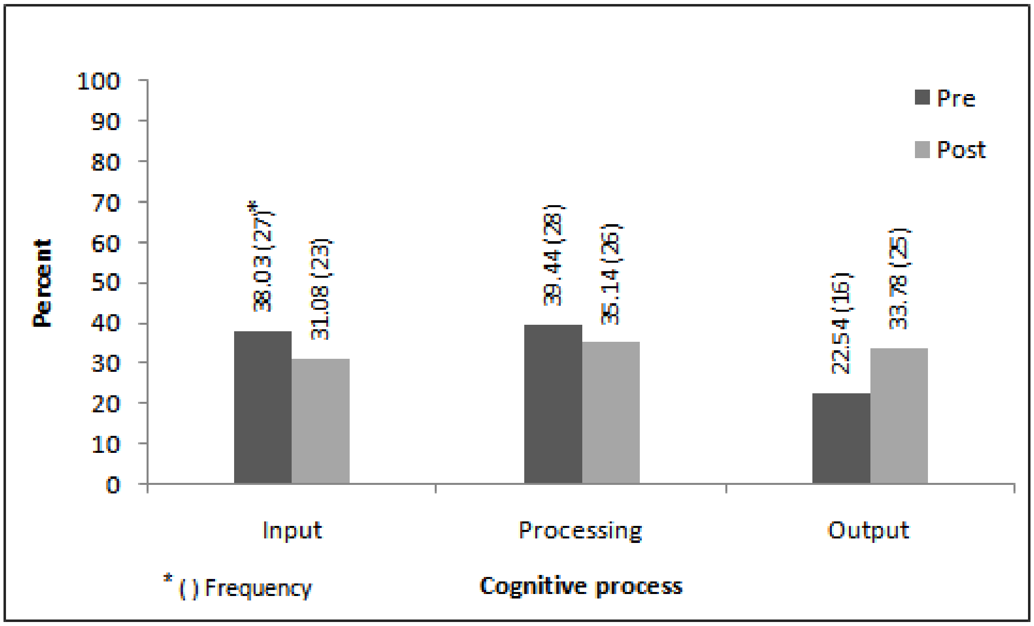


Figure 16. Spatiality of student assessment, by cognitive process

Figure 17 shows that in general, post-assessment items included questions integrating the three components (44.59 percent, 33 out of 74) more than pre-assessment items (32.39 percent, 23 out of 71). Post-assessment items also contained more questions for the categories of cells 12, 17, and 22 (12.16 percent, 9 out of 74) and cells 18, 23, and 24 (20. 27 percent, 15 out of 74) than did pre-assessment items (1.41 percent, 1 out of 71; 12.68 percent, 9 out of 71, respectively). That is, the number of questions requiring higher level spatial thinking increased in the post-assessment items.

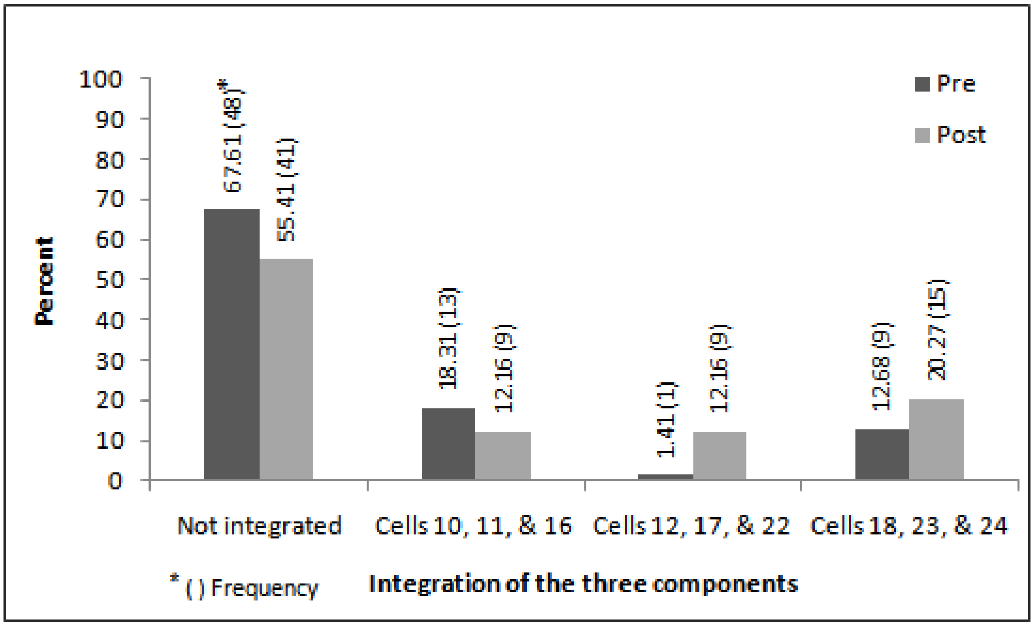


Figure 17. Spatiality of student assessment, by integration of the three components.

As in the lesson objectives, the spatiality of participant-produced assessment items also increased as a result of learning in the workshop. In the next section, I discuss the findings from the teaching and learning procedures portion of the lesson plans and participant narratives obtained by interview, focusing on the degree to which the quantitative and qualitative outcomes corroborate one another.

Participant Narratives

Teaching and Learning Procedures

In analyzing the teaching and learning procedures component of the lesson plans, the focus was on the degree to which the three components of spatial thinking were incorporated in participants' post-lesson plans in comparison to pre-lesson plans. Overall, the three components of spatial thinking were incorporated more explicitly in the post-teaching and learning procedures, supporting the quantitative analysis results. Four implementation types were identified from a qualitative analysis of lesson plans: 1) allocation of lecture time for explicit teaching of spatial concepts; 2) frequent use of spatial concepts; 3) increased use of spatial representations as a teaching and learning tool; and 4) incorporation of higher-level thinking throughout the lesson.

First, participants allocated a block of time in their lecture for teaching spatial concepts explicitly as the following quotes (indicators of explicit teaching italicized):

> As a class, the teacher will lead a discussion and *explicitly teach about what a region is*.

> Before breaking students up into their groups, I will *talk to students about regions and what they are*.

> Present students with some background information on Canada's history and *define key concepts: region, density, etc*.

Second, participants began to utilize spatial concepts much more frequently in their teaching practices, as opposed to teaching them explicitly to students. The concepts of 'overlay,' 'pattern,' and 'distribution' appeared particularly more in the post-lesson plans. Examples include (concepts frequently appeared italicized):

> The two maps could be *overlaid*. Students could then make an inference about the relationship between the two elements.

> The students should then use the *overlay* technique to compare maps of the world's population *density* to maps of the terrain (including *profiles*), records of weather *patterns*, and maps which show various resources.

> The students will also need to look at the *distribution* of people within their specific region and how the first settlers dispersed across the land.

> The teacher will also discuss how language and building type represents the people who have settled the area. To teach this, teacher should use

> *overlay* maps to compare settlement *patterns* based on physical characteristics of land.
>
> Each group would be responsible for presenting to the class with research graphs of weather *patterns* and natural resources of each *region*.

Third, spatial representations were utilized more frequently as a tool for teaching and learning. Not only did the participants use a wider variety of representations for their lecture purposes, but they also had the students use and create representations, such as maps, diagrams, and graphs. The following quotes illustrate such cases (student activities related to using or creating spatial representations italicized):

> The students also need to *create their own charts, graphs, diagrams* to portray information. Complete an example as a class in *making a chart or graph*.
>
> Have students *draw the journey on a map*.
>
> Students also need to *provide pictures and maps* of their specific region.
>
> Each group would be responsible for presenting to the class with research *graphs* of weather patterns and natural resources of each region.

Lastly, higher-level cognitive processes were addressed more in the post-teaching and learning procedures as shown in the following (higher-order thinking processes italicized):

> The students will write in their reflective journals their *speculations about the connections* between landscape, natural resources, and climate and human settlement patterns. The students may *hypothesize* that less people live in colder areas. The students then need to *explain why* they made their conclusions and how that influences today.
>
> The students will still *present their booklets to the class* but an emphasis should be made on their diagrams, charts, maps, etc. They are to *explain what they chose to use and why.*

> Students will then use the worksheets to *compare and contrast* the regions and on a piece of paper write five similarities and five differences.
>
> Combine students into small groups to *compare* what they wrote in the regions and *predicted* what they think Canada would look like if certain geographical changes occurred: Would population groups move? Would people be affected if the climate changed? How?
>
> *Analyze* how Canada's settlement has changed by looking at a map of diffusion since 1700. *Predict* what future changes could occur that may affect the patterns of current settlement.

Rationales for the Lesson Plan Revision

In order to better understand participants' motives, rationales, and focus in revising their initial lesson plans, each participant was asked to explain the reasons for changes of the lesson plans during the interview. Participant narratives verified that they made explicit efforts to incorporate the three components of spatial thinking in their post-lesson plans as a result of learning in the workshop.

As for the aspect of spatial concepts, a participant said:

> I focused on the concepts because after doing the workshop, I found out that *my ideas of some concepts were different from the geography perspective of the concepts.* So, I tried to change as many as I could to fit that.

She realized that some of the spatial concepts have domain-specific meanings and usages that are somewhat different from those in ordinary vocabularies or in other domains. She tried to address this by explicitly teaching such concepts. Another participant said:

> [T]he main other difference [from pre- to post-lesson plans] was just *explicitly teaching what a region is* and then I went on from there. What I really got from the workshop was *not just assuming that my students know what these things are but explicitly describing them.*

What she learned in the workshop was that students are not likely to have sufficient knowledge about spatial concepts as many teachers might assume. Therefore, she would explicitly explain what a region is to ensure that her students know the concept before learning about a world region.

Almost all participants stressed that they tried to increase the use of spatial representations as a teaching and learning tool. It was also found that incorporating more representations was often accompanied by higher-order cognitive processes. For example, the following two quotes represent participants' effort to use maps as a means to help students be able to make comparisons and connections among the content.

> [W]hen [the teacher is] *making the comparison*, instead of just saying it, she can actually show them *a diagram*, which would be another visual to help the students.

> [B]ecause I really loved the idea of *combining maps together to make students make connections.* I think that would help students make connections of why it's warmer in the Southern parts and why they would have those types of resources and industry there. So, that's why I was really focused on adding that.

Several participants used spatial representations to facilitate students' interdisciplinary thinking and critical thinking, as exemplified in the following:

> [T]hey are *making their own and using it [a graph]*… because it gives them more practice. It is related to math as well and spatial thinking and it is used in a social studies context so it is kind of *interdisciplinary*.

> [I]t may be better to have them explore and *have them come to those conclusions themselves through using the maps*.

Participants also made explicit effort to have their students go through higher-level cognitive processes during the lesson. For example, they changed input-level thinking in their pre-lesson plans to processing-level in their post-lesson plans:

> [B]ecause my other assessments that I had had before [in the pre-lesson plan] were kinds of *one region at a time*, and I wanted to be sure that the students could *compare and see how all regions work together* [in the post-lesson plan].

> I used *compare and contrast* because I learned the terms. I learned the different taxonomy, and I wanted to use that. I felt the students would get more out of it than just if I asked them to *name something*.

Participants' effort to incorporate output-level thinking in their post-lesson plans, such as asking students to justify their decisions and to create a representation, was also observed. The examples include:

> [In the pre-lesson plan] I basically said that they *were listening to and creating a booklet and showing it* and that was it. In the second one [post-lesson plan], that part of the assessment was to where they *utilized maps, graphs, and charts in their booklets and while they presented it, they explained their reasoning for choosing* because I gave them the option of choosing which visual.

> I had them just *labeling a map and writing a description of each region* [in the pre-lesson plan]. Instead, they could actually *create a map of the five regions or design one, and then summarize*. So that would be a little bit higher level thinking.

Summary

The results of the analysis of participant-produced lesson plans indicated that the workshop helped preservice teachers enhance their skills to incorporate spatial thinking into their future practices. Increased frequencies of the three components of spatial thinking featured in the post-lesson plans provide evidence. Participant narratives suggested that the learning experiences and activities in the workshop provided them with opportunities to actually practice the required skills to teach spatial thinking. The next section discusses whether such positive educational effects were also found in their dispositional changes, the focus of Research Question 3.

RESEARCH QUESTION 3: DEVELOPMENT OF DISPOSITION

In order to answer the third research question, participants' dispositions toward teaching spatial thinking were measured using the teaching spatial thinking disposition survey (Appendix G). Disposition scores were analyzed using statistical methods (i.e., mean, paired *t*-test, and Cohen's *d*), and these quantitative results were compared with the interview data.

Teaching Spatial Thinking Disposition Survey Score

The survey questionnaire consisted of 32 statements. Each of the statements is associated with a teacher's beliefs about student learning of thinking skills, awareness of spatial thinking and its relationship to geography, or inclinations to teach spatial concepts and skills to use tools of representation.

Participants were asked to indicate their opinions on each statement on a scale from one to four (i.e., 1: strongly disagree; 4: strongly agree), and their disposition scores were calculated by summing up the numbers assigned. As explained in Chapter III, five items (#5, #9, #10, #19, and #27) were scored with a reverse-scale (i.e., strongly disagree: 4; strongly agree: 1) because a strong agreement on these items indicates little likelihood to implement spatial thinking into teaching practices. Therefore, a possible disposition score one could obtain ranged from 32 (1 x 32) to 128 (4 x 32).

The mean score increase from pre-survey (102.38, SD=7.60) to post-survey (115.79, SD=7.63) was 13.42 (95% CI 10.30 to 16.69), and a paired sampled *t*-test revealed that the mean difference was statistically significant ($t = 8.63$; $p < .001$). The effect size was also calculated to ensure the practical significance of the mean difference, and the result ($d = 2.52$) indicated positive educational effect. The criterion for educational effect is $d = .50$ (Wolf 1986). Figure 18 compares distributions of participant's disposition scores between pre- and post-surveys. About 70 percent (17 out of 24) of participants' disposition scores were below 105 on the pre-survey while a similar percent of participants on the post-survey scored above 115.

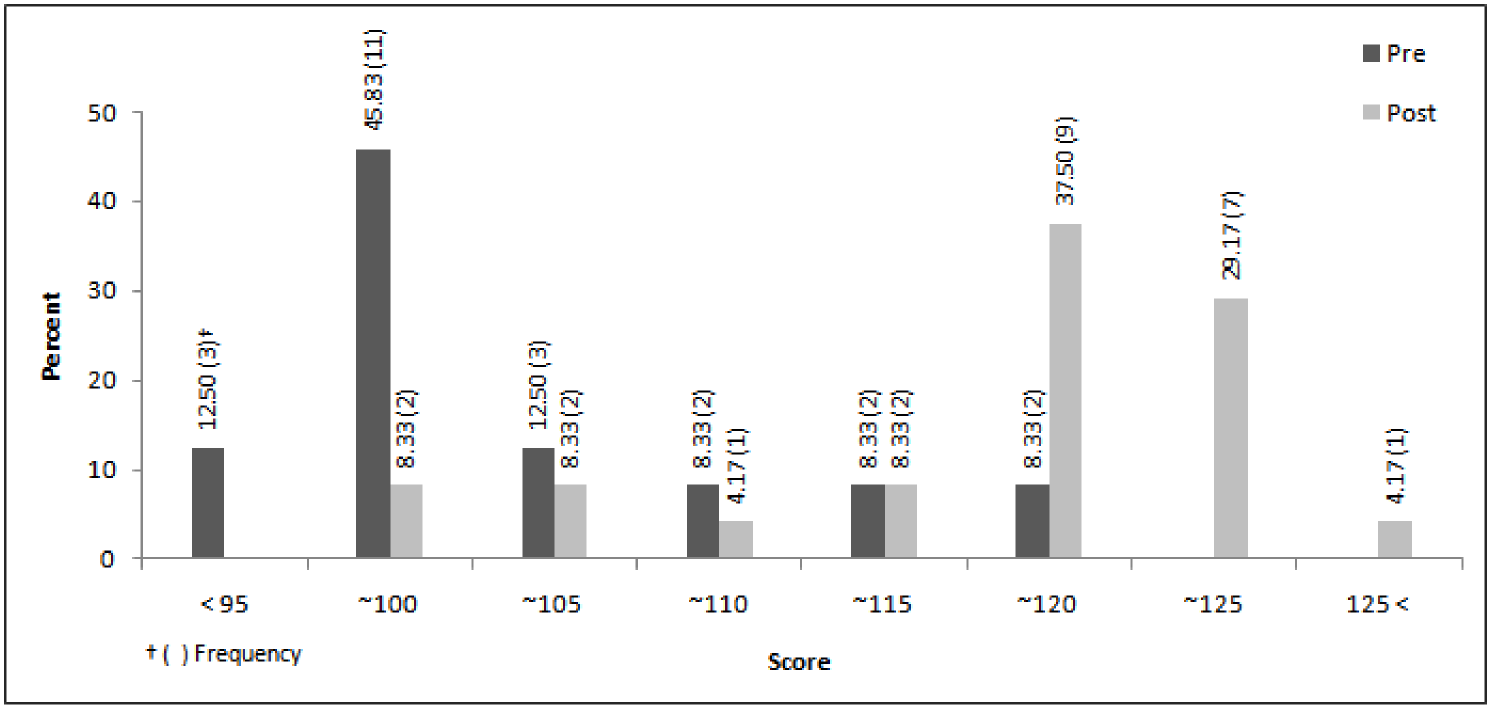


Figure 18. Score distributions on the teaching spatial thinking disposition survey.

Disposition scores were analyzed also by item categories. Teaching thinking skills category (items #1 through #8) is about whether one believes in the teachability of thinking skills; prioritizes developing students' thinking skills; and is willing to stimulate students' thinking in the classroom. Geography and geography learning category (items #9 through #16), on the other hand, asks how a person perceives geography and geography learning and whether he/she is aware of spatial thinking as one of the geographic ways of thinking. Spatial thinking category (items #17 through #23) involves characteristics of a teacher who understands spatial thinking as a powerful skill in a variety of contexts and as an important thinking skill that needs to be nurtured. Spatial concepts and tools of representation category (items #24 through #32) characterizes a teacher who understands the importance of teaching spatial concepts explicitly and having students use and create a variety of spatial representations to develop their spatial thinking skills.

Figure 19 compares average scores between pre- and post-disposition surveys for each item category. Overall, average scores in the pre-disposition survey were around 3.0. Average disposition scores increased for all categories on the post-survey despite the varying degrees of the magnitude by category. The largest increase was observed in the category of spatial thinking (3.0 to 3.6); these items were designed to measure participants' awareness and basic knowledge of spatial thinking.

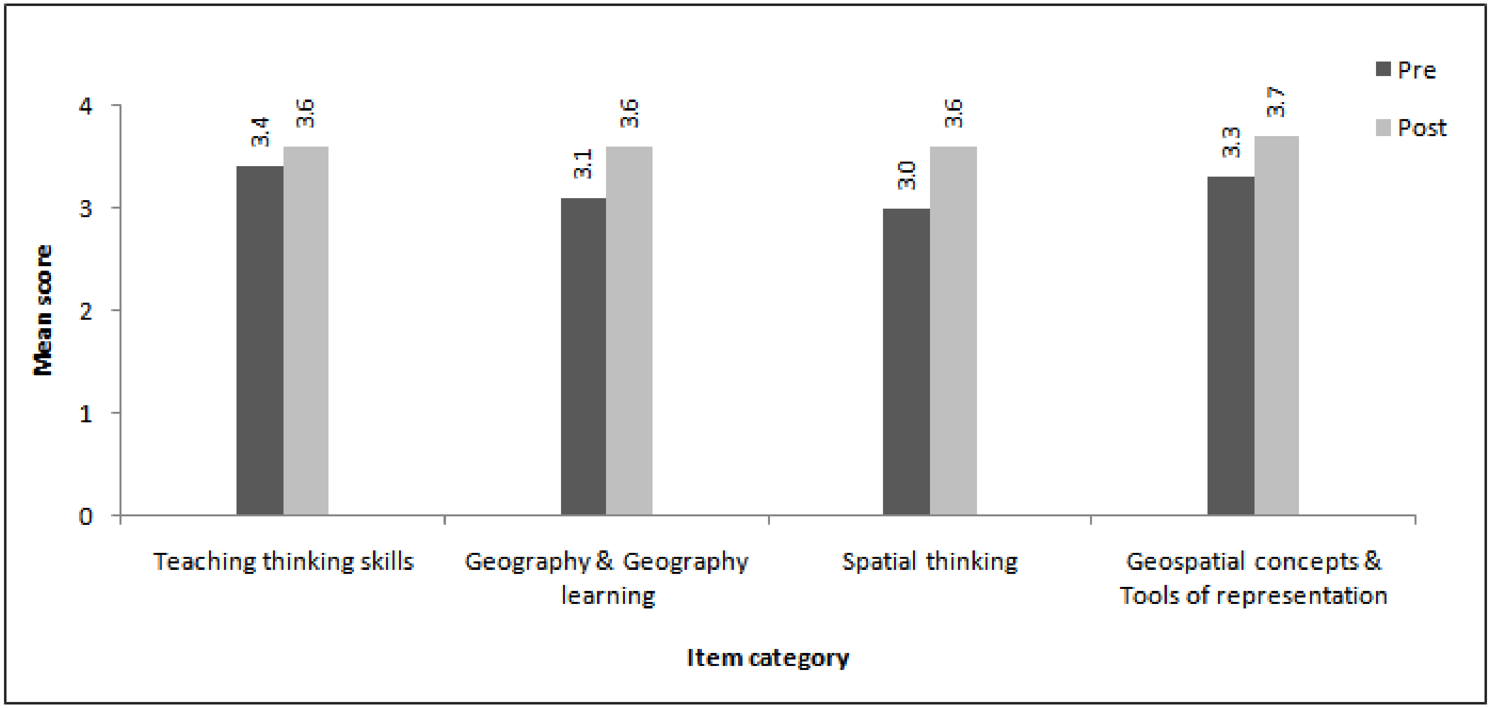


Figure 19. Mean score distributions on the teaching spatial thinking disposition survey, by item category.

Item level changes in the mean disposition scores by item category are presented in Table 10. Overall, score changes in the category of ‘Teaching thinking skills’ were smaller than those in the other three categories. One reason for this may be that pre-survey scores were already very high for some of the items (3.9 for item #1, 3.8 for items #2, #3, and #7), so there was little room for an increase in the post-survey scores. Relatively larger changes were observed, however, on item #4 – My highest priority goal will be developing students’ thinking skills (3.2 to 3.7) and item #6 – I will frequently ask challenging questions and/or tasks (3.3 to 3.8).

In the ‘Geography and geography learning’ category, the purpose of which was to assess participants’ beliefs about and perspectives on geography, three items showed a large increase: item #11 – I believe that geography has much to do with asking questions and solving problems (2.8 to 3.5); item #13 – I believe that understanding spatial patterns and processes is essential in learning geography (3.2 to 3.8); and item #16 – I believe that spatial thinking is an essential part of learning geography (3.3 to 3.9).

Table 10. Mean score change on the teaching spatial thinking disposition survey, by item.

	Survey item	Pre-survey	Post-survey	Change
1	I believe that all students can learn.	3.9	4.0	0.1
2	I believe that thinking skills can be taught.	3.8	4.0	0.2
3	I believe that thinking skills should be taught.	3.8	3.9	0.1
4	My highest priority goal will be developing students' thinking skills.	3.2	3.7	0.5
5	I will feel satisfied when students remember exactly what they've learned.*	2.0	1.8	-0.2
6	I will frequently ask challenging questions and/or tasks.	3.3	3.8	0.5
7	I will like to show students how I think through a problem rather than only the final answer.	3.8	3.9	0.1
8	I will almost always ask students to provide explanations and reasons to support their answers.	3.5	3.7	0.2
	Mean	3.4	3.6	0.2
9	I believe that geography is a mere collection of information.*	2.8	3.2	0.4
10	I believe that geography has much to do with rote memorization of isolated facts.*	2.8	3.2	0.4
11	I believe that geography has much to do with asking questions and solving problems.	2.8	3.5	0.7
12	I believe that geography is the study of spatial aspects of human existence.	3.1	3.5	0.4
13	I believe that understanding spatial patterns and processes is essential in learning geography.	3.2	3.8	0.6
14	I believe that the study and practice of geography require the use of geographic representations, tools, and technologies.	3.3	3.8	0.5
15	I believe that knowing and being able to use spatial concepts are essential in learning geography.	3.3	3.8	0.5
16	I believe that spatial thinking is an essential part of learning geography.	3.3	3.9	0.6
	Mean	3.1	3.6	0.5
17	I believe that spatial thinking is powerful.	3.1	3.8	0.7
18	I believe that spatial thinking is integral to everyday life.	3.0	3.6	0.6
19	I believe that spatial thinking is a skill that is innate.*	2.4	3.3	0.9
20	I believe that spatial thinking skills can be learned by everyone.	3.2	3.7	0.5

Table 10. Continued.

	Survey item	Pre-survey	Post-survey	Change
21	I believe that spatial thinking skills should be learned by everyone.	3.1	3.8	0.7
22	I believe that expertise in spatial thinking draws on spatial skills that are a particular domain of knowledge.	3.0	3.4	0.3
23	I believe that time and practice to develop expertise in spatial thinking within the school system is worthwhile.	3.2	3.7	0.5
	Mean	3.0	3.6	0.6
24	I will explicitly teach concepts of location, place, and region.	3.3	3.5	0.3
25	I will explicitly teach concepts of spatial pattern, scale, density, and spatial diffusion.	3.0	3.5	0.6
26	I believe that spatial representations, such as maps, diagrams, and graphs help students in learning and problem solving.	3.6	3.9	0.3
27	I believe that students can readily interpret maps, diagrams, and graphs without a guided practice.*	3.2	3.0	-0.2
28	I believe that teaching students how to reason from maps, diagrams, and graphs is important.	3.3	3.8	0.4
29	I believe that having students construct (create) their own maps, diagrams, and graphs is important.	3.4	3.8	0.4
30	I will use a variety of spatial representations including maps, diagrams, and graphs in my future class.	3.5	3.8	0.4
31	I will use spatial representations such as maps, diagrams, and graphs to convey a variety of kinds of thinking.	3.3	3.9	0.6
32	I believe that using and creating tools of representations, such as maps, diagrams, and graphs are essential for spatial thinking.	3.2	3.9	0.7
	Mean	3.3	3.7	0.4

* Reversely scaled item (i.e., 1: Strongly agree; 2: Agree; 3: Disagree; 4: Strongly disagree)

Four items out of seven under the category of ‘Spatial thinking’ showed relatively large score increases in the post-survey: item #17 – I believe that spatial thinking is powerful (3.1 to 3.8); item #18 – I believe that spatial thinking is integral to everyday life (3.0 to 3.6); item #19 – I believe that spatial thinking is a skill that is innate (2.4 to 3.3); and item #21 – I believe that spatial thinking skills should be learned by everyone (3.1 to 3.8).

In the ‘Spatial concepts and tools of representation’ category, score increases were high for item #25 – I will explicitly teach concepts of spatial pattern, scale, density, and spatial diffusion (3.0 to 3.5); item #31 – I will use spatial representations such as maps, diagrams, and graphs to convey a variety of kinds of thinking (3.3 to 3.9); and item #32 – I believe that using and creating tools of representations, such as maps, diagrams, and graphs are essential for spatial thinking (3.2 to 3.9).

Participant Narratives

Participant narratives support the survey results that the workshop positively influenced preservice teachers’ dispositions toward incorporating spatial thinking into their future classrooms. Overall, participants indicated they were more willing and inclined to teach spatial thinking to their prospective students, saying:

> I think I have a much better feel for teaching spatial thinking.

> I want to make sure that I am guiding students’ thinking over the content and asking them challenging questions over spatial thinking.

At least two sources of the increased willingness were identified: 1) increased awareness of spatial thinking as an important skill; and 2) the taxonomy of spatial thinking as a tangible tool to incorporate spatial thinking into practice. The examples of the first case include:

> I do believe that *once the preservice teachers are exposed to this information, they will be more willing to do it*.

> I am more motivated to utilize spatial thinking in my future classroom. *It seems like a great strategy*!

The following statements are examples of the second case, in which participants became more willing because they believed that they have a useful tool to help them incorporate spatial thinking more easily.

> After this session, I am more willing to teach spatial thinking *because I have more tools to do so*.

> I am even more willing toward teaching spatial thinking *because it is simple to do if you understand the diagram (taxonomy)*.

> [I am] willing to align curriculum *with the spatial thinking cubes (taxonomy)*. Very cool!

There were also cases of participants who showed enthusiasm for exploring further resources and tools that can help them teach spatial thinking. As one participant said, "I am more willing to search for effective tools for students to use."

Summary

Both quantitative data obtained from the teaching spatial thinking disposition survey and qualitative data from interviews showed that participants became more willing and inclined to teach spatial thinking to their prospective students. Their dispositions increased as they got to know more about spatial thinking, the value of it in a variety of contexts, and the relationship of spatial thinking to learning geography. In the next section, findings that inform the relationship among one's knowledge, skills, and dispositions related to teach spatial thinking will be discussed.

RESEARCH QUESTION 4: THE RELATIONSHIP AMONG PRESERVICE TEACHERS' KNOWLEDGE, SKILLS, AND DISPOSITIONS

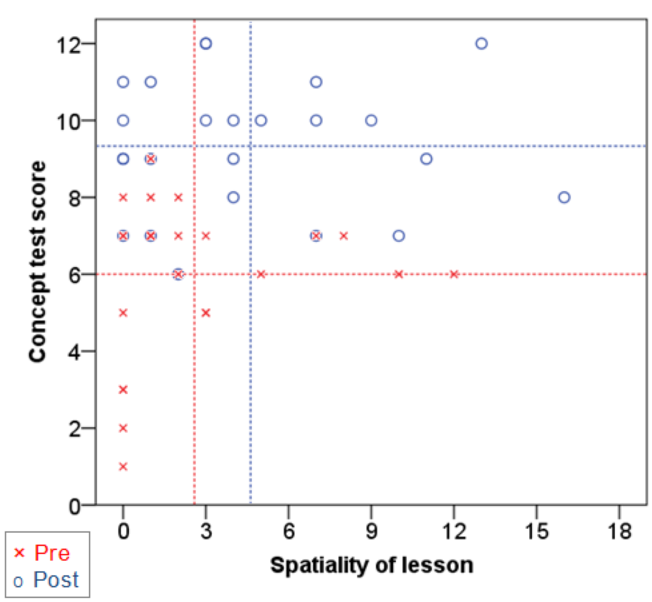
The last research question was first examined by measuring a correlation among the three variables: the spatial concepts test score, the spatiality of lesson plans, and the disposition score. Participants' interviews were then analyzed to understand their perspectives on the relationship among knowledge, skills, and dispositions toward teaching spatial thinking. The degree to which the quantitative results and the qualitative outcomes corroborate one another was examined.

Correlations among the Concept Test Score, Spatiality of Lesson Plan, and Disposition Score

Relationships among participants' knowledge, skills, and dispositions were first examined visually, using scatter plots of the data. As explained in Chapter III, there were 12 items on the spatial concepts test, and the possible score range was from zero to 12. The spatiality of participant-produced lesson objectives and assessment items was quantified using the taxonomy of spatial thinking. The possible spatiality score for each of the lesson objectives and the assessment items ranged from zero (the three components of spatial thinking not-integrated) to three (the three components of spatial thinking integrated with higher-level concepts and cognitive processes involved).

Because participants were required to generate three objectives and three assessment items, the total scores of the lesson plans ranged from zero to 18. The possible range for the total disposition score was from 32 to 128. However, the average disposition scores (i.e., total score/total number of items) were used to simplify the number format on the scatter plots while not affecting the score distribution represented.

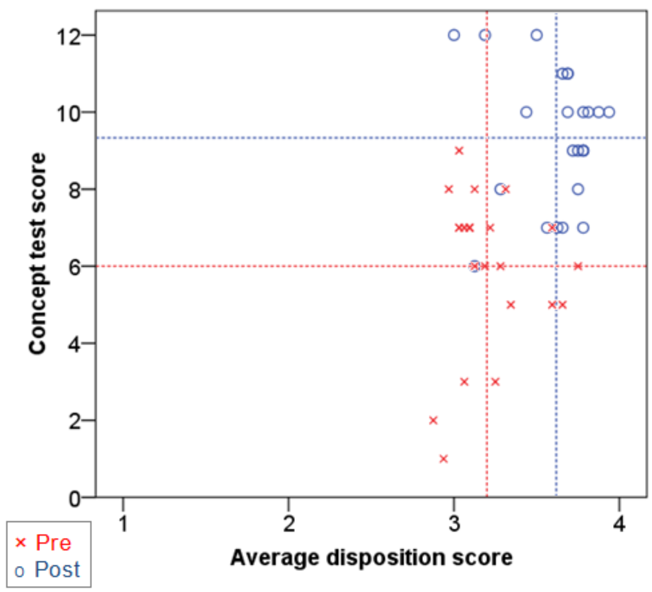
A scatter plot of the concepts test score and the spatiality score of the lesson plans (Figure 20) presents almost no relationship between participants' knowledge about spatial concepts and their skills to incorporate spatial thinking into a lesson. In general, participants' scores on the spatial concepts test were widely distributed while the spatiality scores of their lesson plans were clustered around a low level.



(Note: A reference line added at the total mean of each variable)

Figure 20. Relationship between the concept test score and the spatiality of the lesson plan.

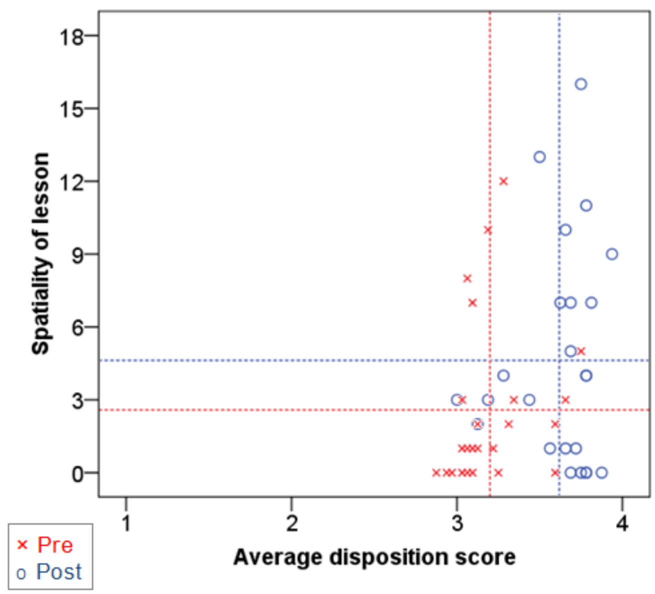
As shown in Figure 21, there was little relationship between one's score on the spatial concepts test and his or her dispositions toward teaching spatial thinking. Overall disposition scores were quite high even on the pre-survey and reached the highest level on the post-survey. A relatively wider range of scores was observed on both the pre- and post-spatial concepts tests.



(Note: A reference line added at the total mean of each variable)

Figure 21. Relationship between the concept test score and the disposition score.

There seems to be a moderate correlation between the spatiality of pre-lesson plans and the pre-disposition score, especially for the low-middle performers (Figure 22). No relationship was detected from the scatter plot of the spatiality of the post-lesson plans and the post-disposition scores, however.



(Note: A reference line added at the total mean of each variable)

Figure 22. Relationship between the spatiality of the lesson plan and the disposition score.

Spearman's rho, a rank-order correlation coefficient, was also calculated to determine whether there was a statistically significant relationship among participants' scores on the spatial concepts test, the spatiality of the lesson plans, and the scores on the teaching spatial thinking disposition survey. The reason for using a rank-order correlation coefficient was because among the three variables, the nature of spatiality of lesson plans is more likely to be ordinal rather than interval in terms of its level of measurement. Table 11 shows the correlations among the three variables. The only statistically significant correlation found was between the spatiality of the pre-lesson plan and the pre-disposition score (ρ = .433, $p < .05$). No other statistically significant correlations were found.

Table 11. Correlations among the measures of participants' knowledge, skills, and dispositions toward teaching spatial thinking.

		Concept test score	Spatiality of lesson plan	Disposition score
Spearman's rho	Concept test score	---	.030	- .068
	Spatiality of lesson plan	. 129	---	- .009
	Disposition score	- .141	.433*	---

Note: Correlations below the diagonal correspond to the pre-test results and the correlations above the diagonal correspond to the post-test results.

* Correlation is significant at the 0.05 level.

Participant Narratives

Participants were asked about their general opinions on the relationship among knowledge, skills, and dispositions toward teaching a subject or specific content. Then, they were asked whether and how their knowledge, skills, and dispositions that were changed from the workshop, if any, affected each other. Although there were no significant correlations among one's knowledge, skills, and dispositions toward teaching spatial thinking, participants' narratives indicated that certain relationships exist among these.

<u>Relationship between Knowledge and Skills</u>

All participants confirmed that the workshop certainly introduced the idea of spatial thinking, which was new to most of them, and increased their level of knowledge about important concepts, saying:

> It gave me all the *knowledge [about spatial thinking] because I didn't have very much to begin with*.
>
> [I]t *taught me new information*, like the new content that I had *never heard of*.
>
> I believe that it *enhanced the knowledge that I might have about spatial thinking*.

Enhanced knowledge also included the awareness of the value of spatial thinking. One of the participants said:

> I think I am even more *aware and know it is more important to teach* and that it is ways of thinking rather than just the content.

The knowledge about what spatial thinking is and its key components, and the understanding of spatial concepts seemed to be prerequisite to develop skills required to teach spatial thinking. One participant explicitly mentioned such a relationship, saying:

> The knowledge kind of added another level to it. It will help me [teach it] *because you kind of have to have the knowledge in order to teach it* and you don't necessarily have to teach even if you have the knowledge … *The more you've come to know this, the more confident you are in teaching it*.

Other participants also stated that they began to know what spatial thinking is so would be able to teach spatial thinking.

> [N]ow *I know more* explicitly what it (spatial thinking) is, and *I can teach it more directly and teach it to students.*
>
> I didn't know what spatial thinking was but now I know that. *I know the importance of it and so I will be able to express that to my students.*

One specific example indicates how the increased awareness and conceptual knowledge would affect the teacher's instructional practices, particularly assessment practices:

> *I am more aware of how to include spatial concepts and spatial thinking in my lessons and then that will affect my instruction, based on the types of questions I give, the types of assessment and activities I will have the students do*. And so, I think it will really affect that aspect of my teaching.

Several participants, though, said that they did not feel as confident in skills to teach spatial thinking as they did for the knowledge about spatial thinking. Examples include:

> I think that the knowledge and the willingness increases and then *the skill is the one that I will have to continue to practice.*
>
> I think *I need more practice and experience* in going through that process.
>
> I just wasn't very aware of it. It was something I might have kind of picked up along the way, sometimes not very clearly... But n*ow I am aware of it.* I need to make sure I include it, and I think of it some ways *personally I need a lot more practice with it, with recognizing on the tests and understanding fully those concepts and being able to recognize them*.

Nevertheless, the enhanced awareness and knowledge definitely motivated them for further pursuit of more information, related skills, and resources for teaching as shown in the following quotes:

> It definitely introduced me to spatial thinking, but *I think I need to learn more about it. Like what all can be considered spatial thinking tools*.
>
> I think I need more information and practice. But it is something that, after the workshop, *I would definitely want to learn more about*. *It's something that I really do want to learn so that I can incorporate it.*

> I am more *willing to search for effective tools for students to use* [to learn spatial thinking].

Relationship between Knowledge and Disposition

Enhanced knowledge and awareness positively affected the participants' willingness and inclination to incorporate of spatial thinking into their future classrooms. One participant explicitly said that exposing preservice teachers to the idea of spatial thinking will be the key to increasing their willingness to teach it.

> I do believe that *once the preservice teachers are exposed to this information, they will be more willing to do it.* As compared to if we were just given a book on spatial thinking, I don't think many would perform it in their classes.

Deeper understandings of spatial concepts and awareness of the spatial perspectives in geography, rather than memorization of facts, also contributed to the increased disposition. As participants said:

> It definitely *helped increase the knowledge*, like what different aspects of spatial thinking are, like pattern, density, and everything. And so I am definitely *willing to teach everything*.

> *I am a little more willing and a little more confident how important it can be rather than thinking that geography is just social studies* that I can just put it aside (because I do not see a lot of values in it).

> I would be *more willing just because I see that it (geography) is not just memorization of facts and taking the test.*

Positive changes in the willingness to teach spatial thinking seem to be also related to the realization that spatial thinking is not something additional to the current curriculum, which would make teachers feel overburdened, but something that can be infused throughout current practices. Such realization increased participants' willingness to incorporate spatial thinking into their future practices as stated by one of the preservice teachers:

> I guess, because as a teacher, there is already so much that you have to teach, so you don't want to worry about teaching a whole other concept. But with spatial thinking, it's something that *I was already thinking that way but not even realizing it* … So if you just touch on it within another lesson, then you are still teaching it, but you are not taking out a week of your time to give to spatial thinking. *You can just incorporate it into everything that you're doing ... And I will be willing to do it*.

<u>*Relationship between Skills and Disposition*</u>

Participants said that they were able to develop certain skills to teach spatial thinking in the workshop as shown in the following quotes:

> [T]he skill part, I feel like *I have been equipped with some skills to be able to teach it*.

> I have *more confidence in teaching spatial skills* to my students.

They often mentioned that watching an exemplary lesson video helped them understand what teaching spatial thinking through geography means. Participants said:

> [D]efinitely seeing the male teacher teach his students and utilize it *helps me to actually make it real*. Like, I can actually do this if he is doing this, then *I can do this in my own classroom*.

> After viewing the video of the teacher giving the lesson to his high school students, *it exposed us to methods of instruction for spatial thinking* … And also, it helped us, using *the taxonomy helped us develop ways of creating spatial thinking questions*.

Once they felt themselves equipped with basic skills required to teaching spatial thinking, it seemed the case that their dispositions toward incorporating such skills to teach spatial thinking definitely increaseed. As one participant stressed:

> I am now *more willing* to incorporate spatial thinking in my classroom *because I know how to and can do so in many ways.*

More specifically, participants pointed out that activities, such as video analysis and question analysis, provided ideas on how they could incorporate spatial thinking into practice and that, in turn, contributed to the development of positive dispositions toward it. Related comments include:

> [The workshop] was more than just what it (spatial thinking) is. *How to actually teach it in the classroom* … that was definitely something I plan on using in my classroom. Also, getting the experience to see the video, see the firsthand *how it can be used* is going to help me apply it to my classroom. And then lastly, [the question analysis] is going to help me come up with the *test questions*, test students' knowledge and skills related to spatial thinking and the content in geography Yeah, all those three things *I am going to definitely apply to future teaching in my classroom!*
>
> [The workshop] also provided some *examples of how to teach it*, so I think *my disposition changed*. I mean, I would always be willing to teach what's best for my students, but the workshop gave us *practical ways to implement that in the classroom*.
>
> [The geography lesson video in session #2] just kind of brought more to my attention and reminded me of what I had known about [spatial thinking from the first session]. I really liked seeing *the example of the teacher and how he did it*. So yes, *definitely more willingness*.
>
> I feel like the workshop will help me question, like, *how I am using graphs and visual representations of geography and social studies in my own classroom*. And also, like *the questioning that I am using, to see if it's effective.* I will try to *incorporate those things as much as possible into my teaching!*

Summary

Quantitative data analysis results did not show any significant relationship among preservice teachers' knowledge, skills, and dispositions except for a moderate positive correlation between the spatiality of the pre-lesson plan and the pre-disposition score. Qualitative outcomes, however, indicated that some relationships certainly exist among these three aspects of teacher characteristics regarding teaching spatial thinking.

CHAPTER V

DISCUSSION AND CONCLUSIONS

This study examined whether explicit instruction in spatial thinking enhances preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking. A one-day workshop was developed by the researcher and delivered to a group of preservice teachers as the intervention of the study. The purpose was to explicitly teach the meaning of spatial thinking, its three key components, and how it can and should be incorporated into teaching practices. Changes in preservice teachers' knowledge, skills, and dispositions as a result of the workshop were measured using a spatial concepts test, participant-produced lesson plans, and a teaching spatial thinking disposition survey. Interviews were conducted to better understand participants' learning experiences in the workshop and to verify the quantitative results obtained through pre- and post-assessments using the three instruments mentioned above. This chapter provides interpretation and implications of the study. The discussion is organized in the same order as the research questions:

1. Does explicit instruction in spatial thinking enhance preservice teachers' knowledge required to teach spatial thinking (content knowledge)?

2. Does explicit instruction in spatial thinking enhance preservice teachers' skills to teach spatial thinking (pedagogical content knowledge)?
3. Does explicit instruction in spatial thinking enhance preservice teachers' dispositions toward teaching spatial thinking in their future classrooms?
4. What is the relationship among preservice teachers' knowledge, skills, and dispositions related to teaching spatial thinking?

As stated in Chapter I, the focus of this study was on the learning experiences of preservice teachers to enhance their knowledge, skills, and dispositions toward teaching spatial thinking (as highlighted in Figure 23) rather than those of students,' which is beyond the scope of this study. The discussion about each of the research questions includes implications for teacher preparation programs in relation to the development of knowledge, skills, and dispositions related to teaching spatial thinking through geography. A summary and conclusions follow, and then suggestions for future research are presented.

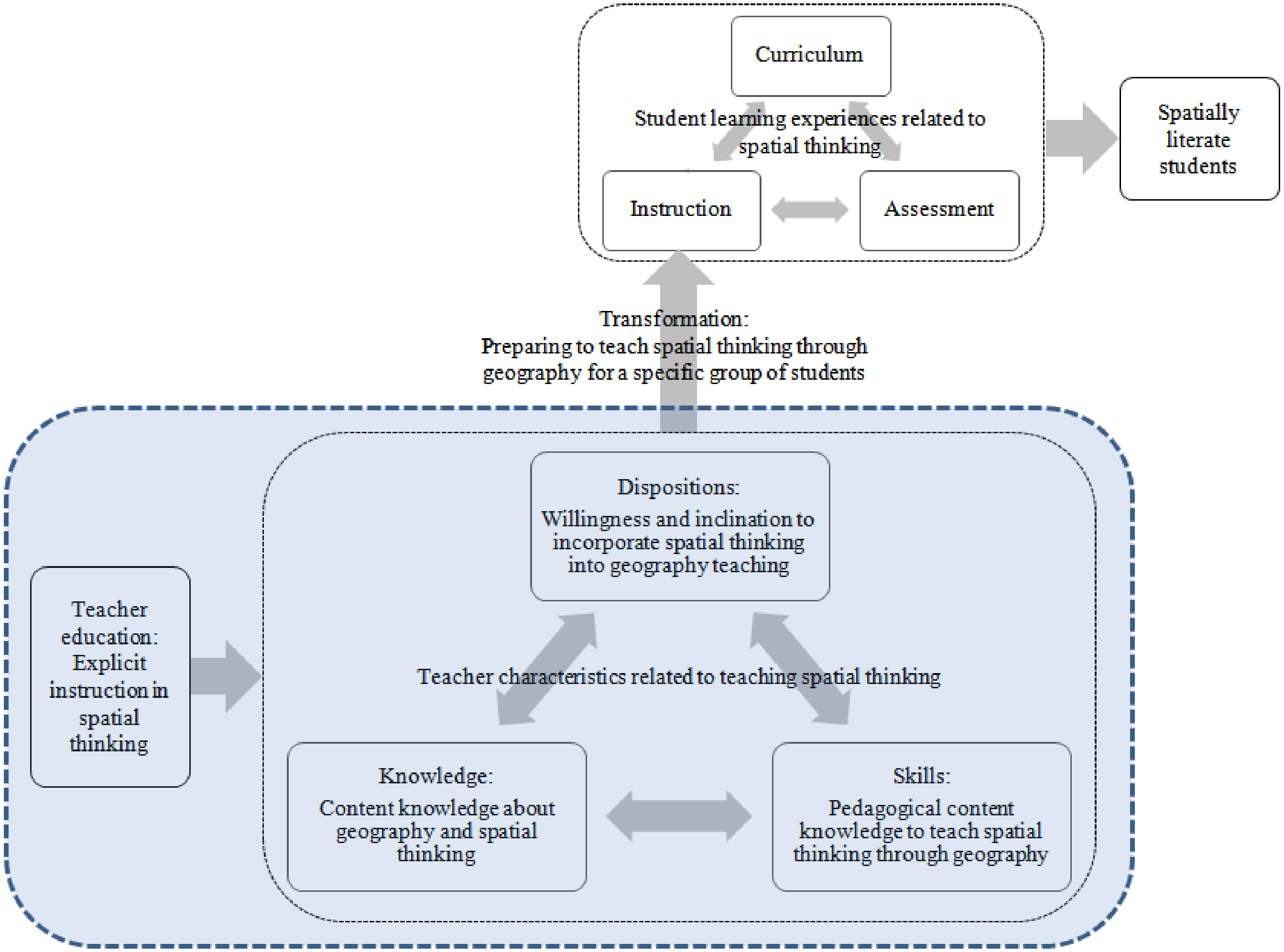


Figure 23. The focus of this study in relation to its theoretical framework.

RESEARCH QUESTION 1: KNOWLEDGE ACQUISITION

Preservice Teachers' Prior Knowledge of Spatial Concepts

This study made one of the first attempts to assess preservice teachers' knowledge of spatial concepts that are required to teach spatial thinking in their future classrooms. In general, preservice teachers lack adequate knowledge required to instruct important spatial concepts to their prospective students. With the exception of two concepts, 'location' and 'distance,' nearly 70 percent of the 24 participants had little understanding of the concepts 'reference frame' (16 out of 24), 'profile' (16 out of 24) and 'density' (17 out of 24); and over 90 percent of the 24 preservice teachers did not know the concept 'overlay' (22 out of 24). This is not very surprising because, as reviewed in Chapter II, research in geography teacher preparation has long pointed out preservice geography teachers' lack of knowledge about location and places let alone their insufficient conceptual understanding.

The findings are also consistent with recent research on the level of understanding of spatial concepts among the general population of college students, the same education level as this study's participants. Marsh, Golledge, and Battersby (2007) demonstrated, in an experimental study, that college students lack high proficiency in abilities to generate spatial relationship terms. Three groups – 6th grade, high school, and college students – were given simple paper and pencil tasks asking them to list all terms that they could think of to describe spatial relationships depicted in diagrams provided to them. Even though college students were able to generate more spatial terms than high school students and 6th graders, only about half of the terms they generated were associated with spatial relationships. In addition, understanding of spatial concepts was not extremely high even in the concept selection task, although the overall performance was higher than in the concept generation task. The authors attributed the overall lack of proficiency in generating spatial concepts to the fact that most of the spatial terms were incidentally grasped rather than intentionally taught. The results of the present study support this finding. For example, all 24 preservice teachers said that they had never heard of the concepts 'overlay' and 'reference frame' or been taught spatial concepts, such as diffusion, density, and location, explicitly.

In addition, this study observed that the level of conceptual understanding varied by concept; and that it generally corresponded to the hierarchy of the concept complexity proposed by the taxonomy of spatial thinking (Figure 6). That is, participants had better understandings of less-complex spatial concepts (i.e., spatial primitives) than more-complex spatial concepts (i.e., complex-spatial concepts). This is apparent from the rank order of percentage correct by concept (from high to low percent) on the pre-test and the corresponding concept hierarchies (Table 12). The fact that some of the complex-spatial concepts (e.g., diffusion, scale, and map projection) showed a higher percentage correct than some of the simple-spatial concepts (e.g., boundary, reference frame) can be attributed to the performance of some participants who were acquainted with the concepts from geography classes taken as a requirement of their teacher certification programs (e.g., introductory human geography, world regional geography, and physical geography).

Table 12. Rank order of percentage correct by concept (from high to low percent) in the pre-test and the corresponding concept categories.

Rank	Concept	Percentage correct (n = 24)	Concept category
1	Location	95.83	Spatial primitive
1	Distance	95.83	Simple-spatial
3	Region	66.67	Simple-spatial
3	Diffusion	66.67	Complex-spatial
5	Scale	54.17	Complex-spatial
6	Map projection	50.00	Complex-spatial
7	Boundary	41.67	Simple-spatial
8	Reference frame	33.33	Simple-spatial
8	Profile	33.33	Complex-spatial
10	Density	29.17	Complex-spatial
11	Pattern	25.00	Complex-spatial
12	Overlay	8.33	Complex-spatial

In the results presented in Table 12, the especially low percentage correct for 'overlay' on the pre-test is noteworthy. According to Battersby, Golledge, and Marsh (2006), map overlay is a concept that can be fairly well grasped prior to high school; and by the level of high school or university, students can apply the concept effectively. Considering that all participants in the present study were senior college students, the results, in which the level of understanding of 'overlay' was found low, seem to contradict Battersby, Golledge, and Marsh's (2006) findings. However, participants' narratives obtained in the present study provide a possible explanation for this result. The participants of this study actually understood the process of adding layers, but they did not know the term to describe it. In the experiments by Battersby, Golledge, and Marsh (2006), students were asked only to solve geospatial problems that could be easily solved with an application of map overlay, not to name or identify the concept representing their strategies. Therefore, it could be the case that some, if not many, of the students who answered their question correctly might not know the concept as 'overlay.' If this is the case, the study finding is rather consistent with the previous research.

The Educational Effect of Explicit Instruction in Spatial Concepts

One of the important findings of this study is the importance of, and probably necessity for, explicit instruction in spatial concepts in preservice geography teacher education. The study results indicated that participants had considerable misunderstandings about some spatial concepts, such as 'map projection,' 'scale,' and 'reference frame,' and these misunderstandings could be corrected through explicit instruction about these concepts in the workshop. Correct conceptions but shallow understanding of spatial concepts was often observed as well, and this also supports the claim that preservice teachers should be taught important spatial concepts in a more explicit manner.

The development of one's understanding of spatial concepts can occur incidentally throughout one's life span (Marsh, Golledge, and Bettersby 2007). However, explicit instruction in spatial concepts seems particularly critical as the concept complexity increases. Actually, some, if not many, spatial concepts are not readily understandable and also are very domain-specific (e.g., map scale, map projection, spatial association, etc. in geography). It can hardly be expected, therefore, that preservice teachers will grasp the meanings and applications of these concepts through incidental learning and out of the context of formal education.

The importance of explicit teaching about spatial concepts is also confirmed by the fact that there was no significant correlation between the number of geography courses the participants had taken in college and their scores on the spatial concepts test. The average number of geography courses that the participants had taken was 1.6. Most of the participants reported having taken one (9 out of 24) or two (9 out of 24) geography courses – mostly introductory human geography, world regional geography, or introductory physical geography – during their college education. However, their knowledge about spatial concepts, especially about complex-spatial concepts, was very limited as discussed in Chapter IV. Most of the participants who had geography course experience pointed out that these concepts were implied in the course rather than explicitly taught. They said:

> [T]he professor would use some spatial concepts and techniques in his teaching, but it was never really referred to as that (spatial thinking). Like, *I had never heard the concepts before this workshop*.

> [Spatial concepts] were definitely in there. *We weren't taught exactly what they were, though*.

> I feel like a lot of the concepts were *covered but not explicitly*.

It may be the case that many geography professors assume that their students already know what those concepts mean. Actually, a few participants said that they were familiar with concepts such as diffusion from the geography texts they used for their coursework, but that term in particular had never been explicitly taught by the instructors:

> In my geography classes, *it was just kind of assumed that you should know that*, but I mean, *most people don't know* what that is.

> We did a lot of diffusion especially in human geography like how people disperse around and what made them move and that kind of stuff. But *I did not exactly know what diffusion means*.

In short, teaching spatial concepts in a more explicit manner in geography classes seems the key to the enhancement of preservice teachers' conceptual knowledge.

Another interesting finding was that the benefits of explicit instruction varied, by concept as shown in Table 13. Participants' performance improvement between the pre- and post-tests was much greater for the questions concerning 'overlay,' 'profile,' 'density,' and 'reference frame' than on those of 'location,' 'distance,' 'boundary,' 'region,' and 'pattern.' For the concepts of location and distance, there was not much room for an increase because almost all participants answered these questions correctly on the pre-test.

Table 13. Rank order of change in percentage correct from pre- to post-test by concept (from high to low percent) and the corresponding concept categories.

Rank	Concept	Percentage correct change (post minus pre; n=24)	Concept category
1	Overlay	70.83	Complex-spatial
2	Profile	45.83	Complex-spatial
3	Density	41.67	Complex-spatial
4	Reference frame	37.50	Simple-spatial
4	Scale	37.50	Complex-spatial
6	Map projection	33.33	Complex-spatial
7	Diffusion	25.00	Complex-spatial
8	Pattern	16.67	Complex-spatial
9	Region	12.50	Simple-spatial
10	Boundary	8.33	Simple-spatial
11	Location	4.17	Spatial primitive
12	Distance	0.00	Simple-spatial

Explicit instruction about spatial concepts seemed to be more effective when: 1) the term itself was novel but the application was familiar and straightforward (e.g., overlay, reference frame); 2) the concept has a domain-specific meaning to be added to the participants' pre-existing ordinary vocabulary knowledge (e.g., profile); and 3) the concept has geography-specific applications to be added to the participants' prior knowledge about the applications in other domains (e.g., scale, density).

Overlay is an example of the first case. Overlay might not be a concept that one would incidentally acquire unless he or she took a GIS course or was familiar with some GIS functions. Once people hear the concept and see its application, for example in GIS or in mathematics, it instinctively makes sense because it is something that people may have done many times even in their everyday lives. As Battersby, Golledge, and Marsh (2006) concluded from a series of experiments:

> Clearly, map overlay is a concept that becomes conceptually easier to grasp and utilize effectively as educational level increases. As was seen in the earlier analysis of students, general student knowledge of map overlay application, ability to use the concept, also appears to be fairly well set relatively early on – prior to high school (Battersby, Golledge, and Marsh 2006, 142).

Another example is 'reference frame,' a coordinate system or set of axes used to measure the position and orientation of objects. Latitude and longitude lines are one of its examples frequently appearing in geography. The concepts of latitude and longitude are those with which most of the participants, as college students, are expected to have an acquaintance. Many of the preservice teachers actually knew what latitude and longitude lines are, but they had insufficient understanding of their functions as a frame of reference. That is, they could tell the difference between the two maps on the test –

one map had latitude and longitude lines while the other did not – but could not think of the term 'reference frame' to explain the difference. After being explicitly taught, however, most of the participants recognized the concept without difficulty.

The concept 'profile,' used in geographic context, is an example of the second case. It is one of the concepts that might not be easily grasped through ordinary vocabulary knowledge. Even though a person knew that profile means 'a side view of objects' as defined in English dictionaries, it is more likely that the person thinks of profile as referring to a biographical description and outline of a person (e.g., personal profile) rather than the cross-section image of a mountain, for example. In addition, geographic usage of the concept of profile is almost exclusively used in connection with a topographic map, which is not a form of map people use on a daily basis. It may not be easy, therefore, to grasp the concept's domain-specific meaning and application without formal education, for example, through a physical geography course experience. Once preservice teachers were exposed to instruction about a topographic profile, how it is created, and what it is used for in geography with an example, their prior knowledge about one of the dictionary meanings of the concept, 'a side view,' quickly adapted to the context. It is probably because the information was something to be added to one's prior knowledge rather than to change it.

Meanwhile, relatively greater score increases for 'scale' and 'density' can be interpreted as a result of knowledge expansion by learning geography-specific applications of the concepts differentiated from the applications in other domains. Among geographers, scale often refers to a map scale whereas it refers to a size, amount, or a measuring system in sciences. It is not easy to understand all of the functions and applications of map scale. Nevertheless, it is basically about the size of geographic features on a map, and that concept is not extremely difficult to comprehend especially with expressions, such as ‘zoomed-in’ and ‘zoomed-out.’

Likewise, the meaning of density in geography little differs from that in other disciplines. Density means the amount of something per unit. Geographers often use ‘density’ to describe frequencies of a geographic feature, either human or physical, appearing per unit area (e.g., population density) whereas it often represents mass density, mass per unit volume, in physics. Despite of the differences across domains, the underlying idea of the concept is the same. That is, those who learned the concept in the physics context would not have difficulty understanding its geographic application. Even for those who have never learned the concept of density, it should not be difficult to comprehend, especially to college students, once it was explicitly taught.

The learning processes involved here can be explained by the theory of ‘three modes of learning’ proposed by Rumelhart and Norman (1976). According to them, learning is not a simple unitary process but involves multiple phases that are qualitatively different. Three different categories of learning were identified: 1) accretion, 2) tuning, and 3) restructuring. Learning through ‘accretion’ represents learning by accumulation of new information onto the existing knowledge base. This type of learning occurs “through appropriate exposure to the concepts to be acquired, with the normal stages of information processing, transforming the information being acquired into some appropriate memory representations, which then is added to the person’s data base of knowledge" (Rumelhart and Norman 1976, 3). Learning through 'tuning,' on the other hand, is more than merely an addition to the existing knowledge, involving continual modifications of the categories and concepts that are used to interpret new information. While the basic relational structure of one's existing knowledge remains the same in tuning, 'restructuring' involves creation of a new knowledge structure. Learning by restructuring is required when the existing knowledge base is not sufficient to account for or organize new information appropriately. This type of learning takes considerable time and effort and is considered "yet a more significant (and difficult) process" (Rumelhart and Norman 1976, 4).

The cases of enhanced conceptual knowledge for 'overlay' and 'reference frame' can be explained as the accretion of knowledge. That is, participants' existing knowledge about the applications and examples of the concepts 'overlay' and 'reference frame' was incremented by newly acquired knowledge about the terms to represent them. The other two cases can be attributed to the mechanisms of learning by 'tuning,' the process of minor modification of the existing knowledge to improve its accuracy, generalize or specify the applicability, and determine the default values associated with specific concepts to make sense of the new information. Explicit instruction about the concepts of 'scale' and 'density' seemed to help participants generalize the applicability of the concepts to a geographic context. In addition, explicit instruction about the concept of 'profile' allowed participants to shift the default value of the term, for example from a biographical outline of a person to a cross-cut image of mountains, when applied to the context of geography.

Educational Implications

As reviewed in Chapter II, in a typical university-based teacher preparation program, preservice geography teachers are expected to acquire sufficient knowledge about geographic concepts through their geography coursework. However, this study found that simply taking one or two geography courses did not guarantee high level proficiency in understanding let alone teaching important spatial concepts. It is not because the geography courses they had taken do not address these concepts at all. Rather, it is because students were not given opportunities to pay enough attention to the concepts, to correct misunderstandings, if any, and to deepen their existing knowledge. Such processes are an essential part of learning (National Research Council 2001). When explicitly taught, as shown in the results of this study, most preservice teachers were able to comprehend, recognize, and explain these concepts, including complex-spatial concepts. Therefore, the first implication of this study is that spatial concepts should explicitly be taught in geography courses. Providing a detailed definition, a prototype, and good examples of the concept would be the most basic but fundamental instructional strategy to teach a concept (National Research Council 2001). Geography professors should explain and highlight domain-specific meanings and applications of spatial concepts so that students develop conceptual knowledge in geography contexts.

Second, this study found quite striking individual differences among the participants in the level of spatial conceptual knowledge. The range of scores for the pre-test was from one to eight. One participant answered only one question correctly. The implication is that instructors should not assume that all college students have a similar level of knowledge of spatial concepts. It is unlikely that the low scoring preservice teachers will be able to teach spatial concepts to their students accurately and effectively. College faculty need to be aware of individual differences in conceptual understanding among their students and try to address these in their courses.

The third implication is similar to the second one. When a geography professor wants to diagnose the students' level of knowledge about spatial concepts, the spatial concepts test developed in this study can be a useful tool. The test may not be considered a standardized test developed through a rigorous validity and reliability routine, but it would serve well as a diagnostic tool in a classroom context. In particular, student responses to the explanation section of each question will provide the instructor with good sources to detect students' misunderstandings of concepts. One striking example of a misunderstanding found in this study was that one participant reasoned that a zoomed-in map (a larger scale map) was the result of 'diffusion' of the map itself. He, therefore, answered 'diffusion' to the question about 'scale.' To most geographers, this kind of misunderstanding is hard to even imagine. It is unlikely that geography professors address such misunderstandings in classes, and therefore students are not likely to have opportunities to correct erroneous ideas. Diagnostic use of the spatial concepts test would help with this kind of problem.

Lastly, the study findings suggest the important role of geography faculty to geography teacher preparation. In order for all three educational implications discussed above to be addressed, it is critical that geography faculty be aware of at least the following three: 1) the emphasis on spatial thinking in current geography education; 2) the system of geography teacher preparation; 3) the importance of concepts and materials they teach in developing preservice geography teachers' ability to teach geography and spatial thinking. Actually, the need for cooperation between geography and education faculty for teacher preparation was pointed out by Bednarz and Bednarz (1995) more than a decade ago although the problem has not significantly improved.

RESEARCH QUESTION 2: SKILLS DEVELOPMENT

Preservice Teachers' Skills to Teach Spatial Thinking

In this study, preservice teachers' skills to teach spatial thinking were measured using the lesson plans they produced before and after the workshop. The degree to which each of the three components of spatial thinking – concepts of space, tools of representation, and processes of reasoning – was addressed in the lesson plan was the focus of the analyses. As reported in Chapter IV, the category of concept that most frequently appeared in the pre-lesson objectives and assessment items was simple-spatial (53.52 percent, 38 out of 71 objectives; 43.66 percent, 31 out of 71 assessment items). Although one might infer from this finding that preservice teachers' skills to incorporate spatial concepts into lessons were adequate, a close look at the data indicate that might not be the case. The concept featured the most was exclusively 'region.' Recall that the materials provided for lesson planning were about regions in Canada. Each section of the material discussed each of the five regions, describing its physical characteristics, cultural characteristics, history, etc., so the participants were likely to use the concept 'region' frequently throughout their lesson plans without purposely teaching spatial concepts. Therefore, the quantitative results may not be an accurate representation of their skills to teach different levels of spatial concepts.

Nevertheless, one encouraging finding is that the percentages of non-spatial concepts were the lowest, not the highest, in the pre-lesson objectives (4.23 percent, 3 out of 71) and assessment items (11.27 percent, 8 out of 71). Jo and Bednarz (2009) found, from analyses of over 3,000 questions presented in the four major high school level world geography textbooks, that a substantial portion of the questions (43.8 percent, 1318 out of 3,010) in those texts focused on non-spatial concepts (e.g., fishery, GNP). Considering the high reliance of K-12 teachers on textbooks for teaching geography, the authors called for special efforts to address aspects of spatial thinking in geography textbooks and other curriculum supporting materials. The present study indicates, however, that the spatiality of concepts addressed in a real classroom lesson could differ from the spatiality of the concepts featured in a text, depending on the teacher's discretion. This, in turn, supports the claim that teacher education maybe key to facilitate student acquisition of one of the key components of spatial thinking.

The study results revealed that most of the preservice teachers who participated in the study did not have sufficient skills to utilize tools of representation for teaching. In the pre-lesson plans, 55 out of the 71 lesson objectives (77.46 percent) and 44 out of the 71 assessment items (61.97 percent) had nothing do with using or creating spatial representations. This should not be surprising, however, considering the typical types of learning students encounter in undergraduate education including teacher preparation courses. As many participants said, their experiences related to using tools of representation for teaching were very limited. The following quotes indicate that in most education classes instructors just touch on spatial representations without focusing on specific skills to use them for teaching:

> It might have been *mentioned once or twice to use maps* … She touched on the eight standards of geography and that was one of them, so *for one day she talked about maps and using them in the classroom*.

> Not really emphasized, *more just introduced*. You touch on them in one chapter and then hurry to the next chapter.

> There might have been *only one week talking about maps and geography*, so very little.

Even though there was an emphasis on using spatial representations in teaching, the power of spatial representations in thinking and problem solving seemed not to be addressed sufficiently. Participants said:

> There was definitely an emphasis of using visual tools, but I had *never heard that term (spatial representation) in relation to spatial thinking.*

> In geography we did use *maps*, but it was not as spatial thinking. *It was more memorization*.

And often times, the use of spatial representations is mentioned, with no opportunities for practice.

> I feel like it (using spatial representations) was emphasized but *just in saying that students need a visual representation*, especially visual learners.

On the other hand, as for the cognitive processes addressed in the lesson plans, the results were not disappointing. The highest percentages in pre-lesson objectives (49.30 percent, 35 out of 71) and assessment items (39.44 percent, 28 out of 74) required processing-level thinking not input-level thinking. This was encouraging because it suggests that preservice teachers have a moderate level of skills to teach higher-level thinking in their future classrooms. Although this study did not examine the source of such skills, the possibility exists that it came from experiences in the curriculum of education courses and the current trends in education that emphasize the inquiry method in teaching. The average number of education courses that the participants had taken was six including a social studies methods course. An examination of the syllabi of these courses revealed that the application of the inquiry method in teaching was one of the main objectives of the methods courses that the preservice teachers were taking at the time they participated in this study.

The Effect of Explicit Practice on the Skills Development

Explicit introduction to the three components of spatial thinking and the opportunity to analyze and evaluate teaching practices from a spatial perspective helped participants enhance their overall skills to teach spatial thinking. Such skills enhancement is demonstrated particularly well by the increased number of complex-spatial concepts featured in the post-lesson plans. Enhanced knowledge about spatial concepts as a result of learning in the workshop promoted the participants' confidence about teaching these concepts and therefore led to more incorporation of them into their lesson plans. The percent decreases for spatial primitives and simple-spatial concepts should be interpreted as a result of a shifting of priority between the concept categories (i.e., from spatial primitives to complex-spatial and from simple-spatial to complex-spatial) rather than decreases in the assessed value of spatial primitives or simple-spatial concepts. This is because the study participants were asked to create only three lesson objectives and assessment items per lesson. If there were no limitations on number of objectives and assessment items that they could list, there might also be an increase in the number of spatial primitives and simple-spatial concepts. No evidence to support or dismiss this possibility is available, however.

As for the use of spatial representations as a teaching and learning tool in geography, there still seems to be much room for improvement. The percentage of objectives and assessment items associated with using and creating tools of representation increased on the post-lesson plans, but 69.01 percent of the lesson objectives (49 out of 71) and 51.35 percent of the assessment items (38 out of 74) were still in the non-use category. One possible reason is because novice teachers find it challenging to create a lesson objective and assessment item that involves spatial representations, such as maps, graphs, and diagrams. That is because it requires comprehensive and integrated knowledge about the content and the ability to select and use spatial representations in an effective way for teaching. It also requires more time, effort, and skill to put things together. As some participants pointed out in the interview, they would need more time and practice to become skillful enough to incorporate aspects of spatial thinking into their teaching practices.

This can be explained by a classic model of teacher professional development suggested by Binko (1989). He identified four essential steps required for teachers to learn new ideas and skills for teaching and to be able to incorporate them into practice effectively: 1) awareness; 2) understanding; 3) guided practice; and 4) implementation.

Awareness is the simplest and most basic step in the process of learning, requiring that teachers only be able to "identify or label an idea, know its name, and be able to distinguish its major features" (Binko 1989, 48). Understanding is a stage where the teacher can explain how the new idea and skills are used and why they are important, and are able to provide a rationale for them. Guided practice and implementation involve transferring the new knowledge and skills into classroom practice and thus very significant. Binko (1989) stressed that the level of skill and confidence that teachers need for an effective implementation of new ideas to their own classrooms cannot be achieved unless they have sufficient opportunities to practice the skills they have been introduced to. It is important that teachers should practice such skills in an environment where they can receive immediate feedback on their progress from teacher educators, peer teachers, or mentors. There is no doubt that guided practice and implementation are more complex processes and so take more time and effort.

The learning experience provided in the workshop was likely to tackle preservice teachers' awareness and understanding of teaching spatial thinking. Participants reported that they are fully aware of what spatial thinking is and how important it is. Although they had opportunities to practice incorporating spatial thinking into designing lessons and assessment questions, it was not sufficient for them to become skillful enough especially with the short duration of the workshop. This suggests that developing expertise in teaching spatial thinking needs extensive experience and practice, which is also consistent with findings from the literature on expert and expertise development in a variety of domains.

It seems that the workshop was successful in equipping participants with skills to teach higher-level thinking. In the post-lesson objectives, percentages for both processing- and output-level cognitive processes increased to a total of about 75 percent (57.75 percent, 41 out of 71 in processing-level; 16.90 percent, 12 out of 71 in output-level). In the post-assessment items, however, an increase was observed only in the output-level category. The decrease for the processing-level category could be, again, because participants had to prioritize a certain level of thinking within the limitation for the number of assessment items that they could create. It was also observed that the level of cognitive processes was better balanced in the assessment items than in the lesson objectives. More specifically, the percentages for the three categories of cognitive processes were: 31.08 percent (23 out of 74) for the input-level, 35.14 percent (26 out of 74) for the processing-level, and 33.78 percent (25 out of 74) for the output-level in the post-assessment items whereas the corresponding percentages in the post-lesson objectives were: 25.35 percent (18 out of 71), 57.75 percent (41 out of 71), and 16.90 percent (12 out of 71), respectively. It seems that participants made more effort to balance between low- and higher-level thinking in designing assessments than they did for creating lesson objectives. This might be a result of their explicit learning experience with assessment questions, analyzing and evaluating geography TAKS questions from a spatial perspective, in the workshop where the importance of balance among different levels of cognitive processes to support student learning was explicitly discussed. If this is the case, a legitimate argument would be that preservice teachers should be given such learning opportunities to ensure such balance when designing lesson objectives and designing questions and assessment items.

Educational Implications

The study findings regarding the effect of explicit attention to spatial thinking on the development of skills to teach spatial thinking have several implications for the focus, methods, and approaches to geography teacher preparation. First, preservice teachers' skills to teach spatial thinking through geography can develop only when the focus of the learning experiences is specifically on the pedagogical content knowledge of teaching spatial thinking through geography not just on the content knowledge of geography or pedagogical knowledge of general strategies of instruction. Participant interviews revealed that most of the preservice teachers had taken only one or two geography courses and a number of education courses, including a social studies methods course. However, their abilities to make connections between the content knowledge learned in their small number of geography courses and pedagogical knowledge learned in education courses were very limited. They were not able to grasp the spatial perspectives of geography and the role of representations in geography learning. As a result, they lacked the pedagogical content knowledge to be able to teach spatial thinking through geography. Despite the short duration of the workshop, just several hours of learning and practicing, the strategy of explicitly focusing on the pedagogical content knowledge of teaching spatial thinking through geography was effective for developing the basic skills required to teach spatial thinking. The importance of teachers' pedagogical content knowledge about a subject matter has been emphasized since Shulman (1986, 1987) devised the term. There has been no research that specifically investigated the importance of pedagogical content knowledge in teaching spatial thinking, however. The present study provides empirical evidence that geography teacher preparation programs should ensure that their student teachers are able to develop pedagogical content knowledge for teaching spatial thinking. This could be done by providing them with sufficient learning experiences that explicitly focus on the topic of teaching spatial thinking in geography contexts.

Not only does the present study confirm the importance of pedagogical content knowledge of prospective teachers to teach spatial thinking, but it also provides insights into some characteristics of learning experiences that can contribute to the development of such pedagogical content knowledge. First of all, it seems critical that preservice teachers have opportunities to see an exemplary classroom lesson in which the three aspects of spatial thinking are infused throughout the lesson. As presented in Chapter IV, many of the participants said that watching a video of an expert geography teacher's lesson and analyzing it from a spatial perspective helped them understand what it means to teach spatial thinking with geography. Actually, most participants did not have previous experiences evaluating classroom teaching. Even for those who had prior experiences of classroom observation and evaluation of teaching practices, the evaluation criteria focused on the teacher's ability to manage the classroom. None of the participants said that they had evaluated someone else's teaching from a content perspective, let alone from a spatial perspective. The implication is clear: preservice teachers need opportunities to observe expert teachers' practices, analyze it from a spatial perspective, and reflect on it to inform their future practices.

Another important component of teacher preparation for implementing spatial thinking in classrooms is that preservice teachers should be equipped with the skills to design questions and assessment items that can facilitate students' practice of spatial thinking. It is well known that questions are significant educational tools, and questions asked either verbally or presented in texts and tests are expected to stimulate students' thinking (Pizzini, Shepardson, and Abell 1992; Vogler 2005; Wilen 2001). Research suggests, however, that not all questions are equally effective in leading students to think (Costa 2001; Hamaker 1986; Mills et al. 1980; Nosich 2005). In geography textbooks especially the cognitive levels required to answer questions were quite low as was their degree of spatiality (Jo and Bednarz 2009). Considering the importance of questions and assessments in education and the low spatiality of the questions in typical curricula materials, it seems critical that teachers be aware of the nature of those questions and be prepared to select, design, and use effective questions to facilitate students' spatial thinking skills. If a teacher's assessment skills are considered a characteristic of expertise, one may not assume that such skills automatically develop with mere repetition of teaching routines. Rather, as with other expertise, deliberate and purposeful practice is necessary. As this study demonstrates, geography teacher preparation programs should provide preservice teachers with opportunities for deliberate practice in developing questions and assessments that stimulate students' spatial thinking.

Another implication of this study for preservice geography teachers' skills development is the importance of providing tangible tools, such as the taxonomy of spatial thinking (Jo and Bednarz 2009). Preservice teachers can utilize and refer to this resource when they get into classrooms. The usefulness of educational taxonomies for teaching and assessing student learning has long been recognized, particularly since the release of the iconic tool developed by Bloom et al. (1956). Most of the study participants were aware of Bloom's Taxonomy, and some had experiences creating higher-order thinking questions using it. However, as pointed out by Jo, Bednarz, and Metoyer (2010):

> Bloom's Taxonomy does not address the two major components of spatial thinking—knowledge about spatial concepts and ability to use tools of representation, limiting its usefulness as a framework to select and design questions to support spatial thinking (Jo, Bednarz, and Metoyer 2010, 51).

The taxonomy of spatial thinking used in this study, on the other hand, addresses the three key components of spatial thinking explicitly. In addition, the three dimensional structure of the taxonomy helps one easily integrate the three components (see Jo, Bednarz, and Metoyer 2010 for concrete examples). Participant narratives strongly support its usefulness:

> I really liked how the chart (taxonomy) was really easy to kind of *find where the questions were placed and on what level*.
>
> I think it's a great way to help focus *where you are at* and how *to improve your questioning* or *what you're expecting the students to do*.

As the quotes illustrate, the taxonomy helped participants evaluate and improve their questions. Also, the taxonomy was useful in ensuring that they were asking various levels of questions and including higher-level thinking questions.

> Like I said earlier, we never analyzed question in class. So I think that using this chart [taxonomy] will *help teachers develop higher level thinking questions for their students* because *most of the time teachers tend to ask lower level thinking questions*.
>
> I think it would be effective to make *sure that you are getting a [wide] range of questions* and that the assessment, whatever assessment you make, it has different levels, like higher-order and lower-order, just a variety of questions being asked.

RESEARCH QUESTION 3: DEVELOPMENT OF DISPOSITION

Preservice Teachers' Dispositions toward Teaching Spatial Thinking

There is emerging research on teacher dispositions, but little attempt has been made to examine dispositional characteristics of teachers related to teaching a specific subject such as geography. Furthermore, nothing is known about teacher dispositions toward teaching spatial thinking. This study addressed this issue. The rationale for particular attention to teacher dispositions was that one can have knowledge and skills to do something – for example, the knowledge and skills to teach with maps – but not be disposed to do so. Recalling the teacher's role as a curricular-instructional gatekeeper (Thornton 2001a), dispositions toward teaching spatial thinking seem to be critical in order for spatial thinking to be addressed in the classroom. A new instrument – teaching spatial thinking disposition survey – was developed to measure the preservice teachers' dispositions that are specifically related to teaching spatial thinking.

As discussed in Chapter IV, the mean disposition scores on the pre-survey for each of the item categories were: 3.4 (out of 4.0) for the 'Teaching thinking skills' category; 3.1 for the 'Geography & Geography learning' category; 3.0 for the 'Spatial thinking' category; and 3.3 for the 'Spatial concepts & Tools of representation' category. The disposition scores for each of the survey items were measured using a four-point Likert scale (i.e., 1: strongly disagree; 4: strongly agree), so the results indicate that overall the participants were fairly disposed to teach spatial thinking. That is, participants seemed to agree that they believe: 1) thinking skills are something that can and should be taught; 2) geography and geography learning are not just about memorization of facts; 3) spatial thinking is important to teach; and 4) they like to teach spatial concepts and to utilize tools of representations for teaching.

However, a closer look at the disposition score by item level suggests that certain beliefs and attitudes of the preservice teachers would hinder them from incorporating spatial thinking. For example, although most of the participants believed that thinking skills can and should be taught (3.8 out of 4.0 for both items #2 and #3), the mean score for item #4 – My highest priority goal will be developing students' thinking skills – was not as high (3.2 out of 4.0). Many of the preservice teachers actually said that they would be satisfied when students remember exactly what they have learned (2.0 out of 4.0 for item #5, reversely scaled). Thus, it is likely that the preservice teachers encourage their students to memorize and recall information; and that the students would not be able to have opportunities to practice higher-level thinking as much.

Another example is related to their conceptualization of geography. Many preservice teachers thought that geography was merely a collection of information (2.8 out of 4.0 for item #9, reversely scaled) and has much to do with rote memorization of isolated facts (2.8 out of 4.0 for item #10, reversely scaled). If a teacher conceptualized geography as a subject to memorize isolated facts, it would be highly unlikely that the teacher would address thinking skills and problem solving skills in his or her geography classroom however much they value the importance of teaching thinking skills.

A third example is represented by participants who believed that spatial thinking is innate (2.4 out of 4.0 for item #19). It is unclear what they thought about spatial thinking before learning about it in the workshop. They might have thought that it was related to some of the items in a psychological test of spatial ability that they may have taken. Or, they might have envisioned spatial thinking as one's sense of direction or wayfinding skills. Whatever their personal conceptions, many of the preservice teachers thought such abilities were something people are born with rather than developed and learned through the education process. This result was interesting because they believed it was the case despite their belief in the possibility of teaching general thinking skills (3.8 out of 4.0 for item #2). This might hinder implementing spatial thinking in schools; if teachers believe that spatial thinking is something that cannot be taught, they will not even try to nurture such skills.

The last example is associated with preservice teachers' attitudes toward teaching specific spatial concepts. The mean disposition score for item #24 – I will explicitly teach concepts of location, place, and region – was quite high (3.3 out of 4.0). However, they were less disposed to teach complex-spatial concepts such as spatial pattern, scale, density, and spatial diffusion (3.0 out of 4.0). Perhaps preservice teachers themselves were not confident about what these concepts meant or they did not know the relevance of these concepts to the subject matter they will be teaching (i.e., social studies and geography). In either case, if teachers do not have an inclination to teach these concepts, students will not be able to have opportunities to learn them.

The Effect of Explicit Instruction in Spatial Thinking on the Development of Dispositions

As observed in the post-survey results, the participants' overall disposition scores increased after the workshop. The mean disposition scores for each of the item categories on the post-survey were: 3.6 for the 'Teaching thinking skills' category; 3.6 for the 'Geography & Geography learning' category; 3.6 for the 'Spatial thinking' category; and 3.7 for the 'Spatial concepts & Tools of representation' category. That is, in general preservice teachers' dispositions toward teaching spatial thinking shifted from the level of 'agree' (3.0 on the scale) to the level of 'strongly agree' (4.0 on the scale). It seems that the workshop reinforced their positive attitude toward teaching thinking skills in general; it helped them understand that geography has much to do with asking questions and problem solving; it enhanced their awareness of spatial thinking as an important skill to be taught; and it increased their willingness to explicitly teach spatial concepts and utilize tools of representation to facilitate students' spatial thinking skills.

These positive changes in dispositions were also demonstrated by the item level analysis. The greatest score change was observed for item #19 – I believe that spatial thinking is a skill that is innate. Explicit instruction in spatial thinking changed their beliefs about spatial thinking from 'cannot be taught' to 'can be taught.' Relatively large score increases were found for items #11, #17, #21, and #32. By the end of the workshop, preservice teachers began to realize that: 1) geography has more to do with asking questions and solving problems than mere rote memorization (from 2.8 to 3.5 for item #11); 2) spatial thinking is powerful (from 3.1 to 3.8 for item #17); 3) spatial thinking should be learned by everyone (from 3.1 to 3.8 for item #21); and 4) using and creating tools of representations are essential to spatial thinking (from 3.2 to 3.9 for item #32).

It is noteworthy that explicit instruction about spatial thinking in relation to geography affected not only their beliefs about spatial thinking but also the conceptualization of the subject matter of geography. Participant narratives showed such changes as in the following:

> I normally thought about geography as maps, places, and just rote memorization of facts. But I really *began to think how much more goes into it (geography) and how much more you can learn in geography*.
>
> I think my perspective did change, just because the way that geography has always been taught to me, it never required a lot of thinking. It was kind of like, "Here is the fact. You need to know it so you can tell me later." But with the workshop, it actually *made me really think geography is more than that (memorizing facts) and I really like that* because I am not the kind of person that wants to just be told information and have to recall it. I want to be able to *analyze on my own and come up with my own interpretation of it*.
>
> My attitude is thinking geography just in terms of where is this place on a map, which is important because we have to know where states and countries are, but I think the workshop *helped reaffirm that geography goes so much further than that. There are so much other important parts of geography*.
>
> Because of my human geography class, I knew that it (geography) wasn't just maps and states and capitals. I thought it was mostly people and the movement of people and why they would move those places. But after the workshop, I realized that *it's also more a way of thinking and a way of processing ideas*.

Educational Implications

The findings regarding the development of preservice teacher dispositions toward teaching spatial thinking provide at least three implications for teacher education. First, preservice teachers need to be explicitly exposed to information about the nature of spatial thinking, its importance in a variety of contexts, and its teachability. This is because strong dispositions toward implementing spatial thinking into classroom contexts seem to develop only when the preservice teacher sees the value of spatial thinking explicitly. Although not negative (i.e., 'disagree' or 'strongly disagree' on the survey scale), the mean score for the category of 'Spatial thinking' (3.0 out of 4.0) was lowest in the pre-survey. This changed to 3.6 (out of 4.0) in the post-survey, indicating that the low degree of disposition before the workshop was likely due to a lack of awareness and knowledge about spatial thinking rather than reflecting a particular belief system. As a participant said:

> [M]y willingness, the workshop really showed me *how important it (spatial thinking) is, and how you can really help the students learn it better*. *So I am really willing* to learn it and to incorporate it.

Exposing preservice teachers to such new information does not even require a long time. The workshop delivered in this study took only about four hours, and it was sufficient to enhance preservice teachers' dispositions to the most positive level. It should not, therefore, be difficult to implement with the current practices of teacher preparation.

Second, the curriculum for teacher preparation should pay more attention to teaching the skills necessary to use representations for instruction rather than simply emphasizing their importance. As discussed in the previous section, the education courses for preservice teachers do not adequately address how to use spatial representations, such as maps, diagrams, and graphs, as an aid to student learning. This practice may explain the relatively higher disposition score on the pre-survey for item #30 – I will use a variety of spatial representations, such as maps, diagrams, and graphs in my future class (3.5 out of 4.0) but the low level of skills to incorporate tools of representations in their lesson objectives (77.45 percent, 55 out of 71 in non-use category) and the assessment items (61.97 percent, 44 out of 74 in non-use category). As observed in the pre-disposition score, preservice teachers already had sufficient willingness and inclination to incorporate spatial representations. In addition, they were aware that students cannot readily interpret spatial representations without guided practice (3.2 out of 4.0 for item #27), indicating that they fully understood the importance of teaching how to use and create representations. Teacher preparation for using spatial representations should focus on the development of related skills rather than just enhancing awareness of their importance.

Lastly, teacher dispositions toward spatial thinking should be assessed and analyzed in greater detail and a more careful manner. As discussed, preservice teachers had generally positive dispositions toward teaching general thinking skills but this did not guarantee that they would value and teach spatial thinking to the same degree. Also, the results of the analysis at the item category level suggested that preservice teachers had adequate dispositions related to spatial thinking, but the analysis at the item level revealed that preservice teachers' dispositions were not sufficient regarding some of the key behaviors, attitudes, beliefs, and willingness required to be able to teach spatial thinking. If an instructor or a teacher education program uses the instrument developed in this study to assess the student teachers' dispositions to make a decision about the teacher preparation curriculum, a detailed analysis at the item level would be desirable to obtain a more accurate picture of the issues that need to be addressed.

RESEARCH QUESTION 4

The Relationship among Preservice Teachers' Knowledge, Skills, and Dispositions

As discussed in Chapter IV, a statistically significant correlation was found only between the pre-disposition scores and the spatiality of the pre-lesson plans ($\rho = .433$, $p < .05$). No significant relationships were detected between the pre-concept test scores and the spatiality of pre-lesson plans; or between the pre-concept test scores and the pre-disposition scores. The lack of a correlation between participants' knowledge about spatial concepts and their skills to incorporate spatial thinking into a lesson could be interpreted as an example of the instance where knowing something does not necessarily mean being able to teach it effectively. A teacher's knowledge of spatial concepts is part of the content knowledge of teaching spatial thinking whereas the skills needed to incorporate the three components of spatial thinking into a lesson plan are pedagogical content knowledge. If that is the case, the result makes sense because, as emphasized by Shulman (1986, 1987), content knowledge and pedagogical content knowledge are different categories of knowledge; possessing one type does not guarantee a high-level of the other.

The lack of a correlation between concept knowledge and disposition toward teaching spatial thinking can also be explained by the general premise that a teacher can have knowledge about something but not be disposed to teach it. This result can also be attributed to the nature of the instrument – teaching spatial thinking disposition survey – that includes items not only about the inclination to teach spatial concepts but also about general beliefs about teaching thinking skills, the subject matter of geography, etc. That is, a preservice teacher's disposition score could be fairly high even though one did not have a particular willingness to teach spatial concepts.

The significant correlation between the skills to incorporate spatial thinking and the dispositions toward teaching spatial thinking was an interesting finding. It suggests that preservice teachers had a greater inclination and willingness to teach something if they believed they knew how to teach it.

None of the relationships examined was found significant in the post-assessment of knowledge, skills, and dispositions despite significant enhancement in all of these three measures that were observed after the workshop. The fact that there was no relationship between knowledge of spatial concepts and the skills to incorporate spatial thinking may be evidence that knowledge acquisition and skills development do not occur at the same rate within an individual. In other words, knowledge about spatial thinking can develop faster than do the skills to teach it. Actually, several participants pointed out that although they felt confident about their knowledge about what spatial thinking is, how important it is, and what concepts are important to teach, they would need more time to be able to incorporate that knowledge into their teaching. A three-dimensional visualization of the pre- and post-assessment results (Figure 24) clearly shows this. The increases in the concepts test score and in the average disposition score of participants on the post-assessment are clear in comparison to the relatively small increases in the spatiality score of their lesson plans. Participants' dispositions toward teaching spatial thinking were developed to the highest level after the workshop whereas most of the participants' skills to incorporate spatial thinking into a lesson still remained at the low level. Again, Binko's (1989) model of the skill development of teachers can explain this. There is a significant difference between 'being aware' of spatial thinking and a deeper 'understanding' of it. Likewise, awareness and understanding of spatial thinking must be different from 'being able to implement' it into teaching practice. Awareness and understanding seem to be prerequisite for, but not guarantee, the development of relevant skills.

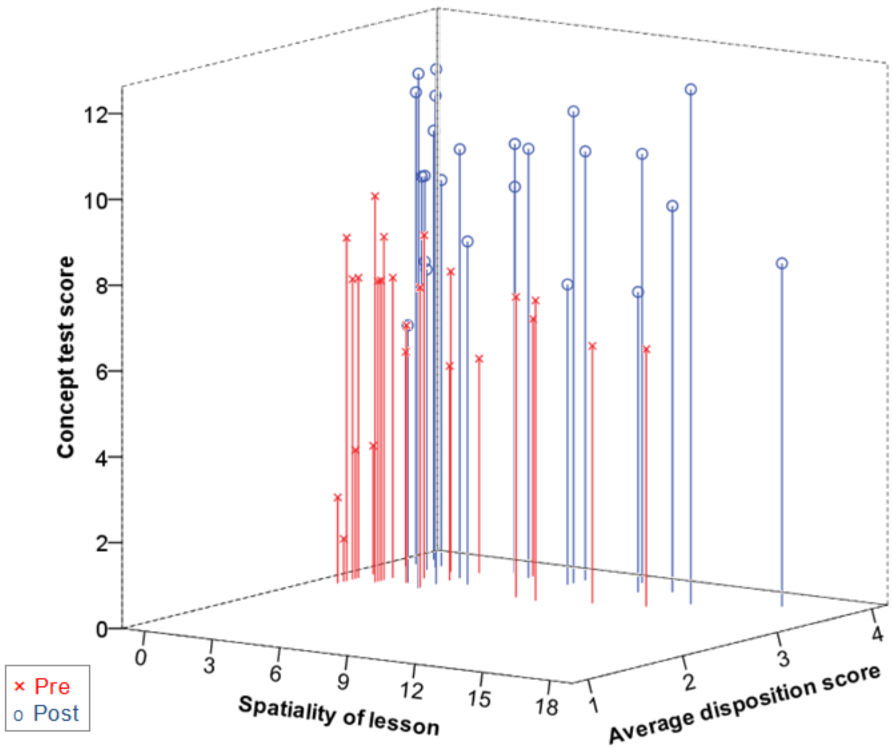


Figure 24. Changes in participants' knowledge, skills, and dispositions.

No relationship between knowledge and disposition in the post-assessment can also be explained similarly. Considering the extremely high scores on the post-disposition survey across almost all participants but the relatively wider distribution of concepts test scores, it could be that dispositions develop even faster after reaching a threshold than does knowledge. This is supported by the participant narratives such as:

> I think *I need more information and practice.* But it is something that, after the workshop, I would definitely want to learn more about. *It's something that I really do want to learn* so that I can incorporate it.

Participants began to know about spatial thinking and that awareness and their basic knowledge about spatial thinking acquired from the workshop greatly increased their dispositions toward teaching it. There is still, however, room for the development of more knowledge, learning more concepts, and deepening concept understanding.

Although the analysis of quantitative data revealed almost no correlations among preservice teachers' knowledge, skills, and dispositions, qualitative data indicate that some relationships certainly exist. The analysis suggests that awareness of spatial thinking and a basic level of knowledge about spatial concepts are the most critical factors that affect the development of related skills and dispositions. As a participant said:

> Well, I didn't know anything about it (spatial thinking) before, so I wouldn't have been able to teach it. Or, I might have taught it but not realizing it. And then, *knowing about it, knowing how to use it, and then yeah, I am willing because I know how to.*

The following quote reveals the close relationship between the level of knowledge about spatial thinking and the degree to which the participants are disposed to teaching it.

> I *definitely know the background knowledge of spatial thinking* and I am *definitely willing to*, from your workshop, incorporate that … I guess I *need to think about it more and study more on how to bring that into the classroom*.

This participant's statement indicates that she became more willing based on the new knowledge she acquired although she did not feel as confident with her skills. Therefore, this suggests that knowledge, skills, and dispositions toward spatial thinking are closely related and significantly affect one another.

Educational Implications

Little correlation in the pre-assessment supports Shulman's (1986, 1987) theory that different categories of knowledge serve as the base for teaching. Although not mutually exclusive, one category of knowledge (i.e., content knowledge) does not guarantee automatic development of another (i.e., pedagogical content knowledge). One implication of this for teacher preparation is evident: the focus of teacher education for spatial thinking should not only be on the development of content knowledge but also on the development of pedagogical content knowledge.

Nevertheless, it does not seem that pedagogical content knowledge develops at the same rate as content knowledge. That is, acquisition of pedagogical content knowledge related to teaching spatial thinking seems to require more time and practice than the acquisition of content knowledge. Therefore, the second implication is that teacher preparation programs should provide preservice teachers with more time and opportunities to develop pedagogical content knowledge related to teaching spatial thinking.

By definition, pedagogical content knowledge cannot develop out of a domain-specific context. Therefore, the goal of developing preservice teachers' pedagogical content knowledge can only be accomplished through collaboration between individual geography instructors and those responsible for teacher preparation. This, in turn, calls for a systematic reform in the syllabi of both geography and education courses that preservice geography teachers take. It should not be forgotten, however, that developing content knowledge also requires communication and collaboration between geography faculty and education faculty. Strategies that would be effective for the development of content knowledge include:

- Education courses, including social studies and other methods courses, introduce spatial thinking as a powerful way of thinking in a variety of subjects, such as mathematics, sciences, and geography, to ensure a basic level of awareness of what spatial thinking is and how important it is;
- Geography courses point out spatial perspectives and spatial analyses in geography so that the students, including preservice geography teachers, recognize the role of spatial thinking in geography, geography learning, and problem solving.

As for the development of the pedagogical content knowledge required to teach spatial thinking, however, neither existing education courses nor typical geography courses are in a position to accomplish this goal. It is not feasible in an education course, for example social studies methods, because a social studies methods course must cover all components of social studies, such as history, civics, economics, government, as well as geography. Considering the substantial time and practice required to develop pedagogical content knowledge of spatial thinking, it seems almost impossible that preservice teachers could learn it within the short period of time allocated to geography in social studies methods courses. It does not seem to be feasible to address the pedagogical content knowledge of teaching spatial thinking in general geography courses either. Courses, such as introductory human geography, world regional geography, and introductory physical geography, that preservice teachers typically take are targeted to a diverse background of students not just preservice geography and social studies teachers. Most of the students may have no interest in how to teach geography and spatial thinking in K-12 classrooms. An ideal solution to the problem would be offering geography education courses which focus exclusively on the development of geographical pedagogical content knowledge. Teaching spatial thinking through geography could easily and effectively be infused into the curriculum of such a class. It would also be possible to provide more time and practice opportunities because the class would be focused on the development of pedagogical content knowledge rather than just on geography disciplinary knowledge. The expected audience, geography and social studies teachers, makes this possible.

SUMMARY AND CONCLUSIONS

Geography can be a valuable subject to teach spatial thinking not only because fostering a generation of spatially literate citizens is one of the main goals of geography instruction (Geography Education Standards Project 1994; National Research Council 2006), but because geography has traditionally emphasized spatial perspectives and analysis (Downs 1994; Golledge 2002; Hanson 2004; Solem, Cheung, and Schlemper 2008). Although the research on spatial thinking in geography education in the last decade indicates ongoing efforts to incorporate spatial thinking into geography classrooms, the focus has mostly been on the curriculum, in a broad sense, including formal courses, students' classroom activities, and technologies implemented to support spatial thinking rather than on geography assessment or the education of geography teachers.

Numerous studies support the claim that preservice teacher education is the key to success in implementing educational innovations. If spatial thinking is something new but important to the school curriculum, it is essential that spatial thinking be addressed in the curriculum of teacher preparation programs. However, no research has proposed a model for preparing prospective teachers to acquire the knowledge and skills required to teach spatial thinking and to develop appropriate dispositional attitudes about incorporating this important skill into their classrooms. The literature on effective teacher education indicates that the curriculum of teacher preparation programs should infuse key concepts and ideas about spatial thinking throughout their courses and practices in a more coherent, integrated, and explicit manner.

The major objective of this study was to examine the effect of explicit instruction on the development of preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking. The four research questions were:

1. Does explicit instruction in spatial thinking enhance preservice teachers' knowledge required to teach spatial thinking (content knowledge)?
2. Does explicit instruction in spatial thinking enhance preservice teachers' skills to teach spatial thinking (pedagogical content knowledge)?
3. Does explicit instruction in spatial thinking enhance preservice teachers' dispositions toward teaching spatial thinking in their future classrooms?

4. What is the relationship among preservice teachers' knowledge, skills, and dispositions related to teaching spatial thinking?

A one-day, approximately four-hours long, workshop – Teaching Spatial Thinking with Geography – for preservice teachers was developed as the intervention of this study in order to explore how to promote preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking. The primary focus of the workshop was to provide an explicit opportunity to learn about spatial thinking and to practice skills required to incorporate spatial thinking into their classroom. Three assessments were used to examine changes in participants' knowledge, skills, and dispositions, before and after the workshop: a spatial-concepts test, a teaching spatial thinking disposition survey, and mini-lesson plans. Individual interviews were conducted to obtain a deeper understanding of participants' learning experiences during the workshop.

The first research question was initially examined using statistical analyses (i.e., mean, paired *t*-test, Cohen's *d*) of participants' scores on the spatial concepts test. Participant narratives about the test were then analyzed to examine whether, and to what extent, the qualitative outcomes supported the statistical results.

In answering the second research question, participants' skills to teach spatial thinking were measured through an analysis of lesson plans they developed during the pre- and post-tests conducted before and after the workshop. A taxonomy of spatial thinking proposed by Jo and Bednarz (2009) was used as a tool to evaluate the spatiality of the lesson plans. The spatiality of lesson objectives and student assessment items was quantified and analyzed using descriptive statistics, such as frequency and percentage.

Teaching and learning procedures of the lesson plans were analyzed qualitatively by unitizing and categorizing the data. Participants' narratives about their lesson plans obtained through an interview were also examined. These qualitative outcomes were then compared to the quantitative results.

In order to answer the third research question, participants' dispositions toward teaching spatial thinking were measured using the teaching spatial thinking disposition survey. Disposition scores were analyzed using statistical methods (i.e., mean, paired *t*-test, and Cohen's *d*), and these quantitative results were compared with the interview data.

The last research question was first examined by measuring the correlations among the three variables: the concepts test score, the spatiality of lesson plans, and the disposition score. Participants' interviews were then analyzed to understand their perspectives on the relationship, if any, among knowledge, skills, and dispositions toward teaching spatial thinking. The degree to which the quantitative results and the qualitative outcomes corroborate one another was examined.

The major findings of this study are as follows:

First, explicit instruction about spatial concepts is necessary to develop preservice teachers' knowledge required for teaching spatial thinking through geography. Spatial thinking cannot occur without knowing spatial concepts, and therefore students should learn about spatial concepts to develop their spatial thinking skills. However, it is unlikely that the students can develop sufficient knowledge of these concepts unless they are taught accurately and effectively. This study found that preservice teachers' knowledge about spatial concepts was limited, suggesting their limited ability to teach them in the future. Geography coursework does not always guarantee students' conceptual development. Rather, explicit instruction about spatial concepts, with a detailed definition, a prototype, and best examples, was found to be an effective strategy to enhance preservice teachers' knowledge of spatial concepts and to correct their misunderstandings.

Second, the skills development required to teach spatial thinking should be approached as the development of pedagogical content knowledge. The skills to incorporate the key components of spatial thinking into practice are not an automatic result of gaining geography content knowledge or general pedagogical knowledge. This study found skills development for teaching spatial thinking requires more time and practice than does knowledge development. It also requires special and explicit learning experiences, which focus on concrete examples of teaching spatial thinking in a domain context (e.g., an exemplary geography lesson video where the teacher facilitates students' spatial thinking while teaching geography) and opportunities to deliberately practice (e.g., evaluating test questions from a spatial perspective). Introducing tangible tools, such as a taxonomy of spatial thinking, can facilitate these practices.

Third, dispositions toward teaching spatial thinking should be differentiated from dispositions toward teaching general thinking skills. Dispositions can be developed sufficiently only when there is explicit instruction in spatial thinking. A closer look at the disposition score by item level suggests that some of the beliefs and attitudes that the preservice teachers possessed would hinder them from incorporating spatial thinking in their classrooms. As shown in the extremely high disposition scores after the workshop, this problem can be addressed by providing information about spatial thinking, such as what it is and how important it is, in an explicit manner.

Fourth, although explicit instruction about teaching spatial thinking contributed substantially to the preservice teachers' acquisition of knowledge and skills and the development of positive dispositions toward teaching spatial thinking, each of these components develops at a different rate but affect each other. The disposition develops fastest once preservice teachers are exposed to basic information about spatial thinking. The knowledge of important concepts develops fairly quickly although deeper understanding definitely takes more time. Skill acquisition requires more time, experience, and intensive practice than the other two components. Again, special attention to the development of pedagogical content knowledge of teaching spatial thinking in teacher preparation is needed.

Finally, a promising approach to the development of preservice teachers' pedagogical content knowledge would be to offer geography education courses, not general geography or methods courses, in which the focus is explicitly on teaching geography with an emphasis on spatial thinking. Considering the time and practice required to develop sufficient skills and the importance of explicit attention to spatial thinking in the context of geography education, neither general geography courses (e.g., introductory level human geography, world regional geography, and physical geography) nor social studies methods courses seem to be capable of addressing all of these requirements. Offering geography education courses may require a systematic reform of current teacher preparation programs and also more collaboration and communication between geography faculty and education faculty. Bednarz and Bednarz (1995) urged such effort more than a decade ago, but this has yet been addressed significantly.

SUGGESTIONS FOR FUTURE RESEARCH

This study attempted to devise a method for developing students' spatial thinking skills from the perspective of teacher preparation. Although the study provided valuable insights into the characteristics of geography teacher preparation that can contribute to the enhancement of preservice teachers' knowledge, skills, and dispositions toward teaching spatial thinking, further research is required.

First, a reasonable step would be to examine inservice practices of the study participants to see how their enhanced awareness of spatial thinking and knowledge about spatial concepts are reflected in their teaching practices. Such a longitudinal study would help reevaluate the effectiveness of the workshop in a real-world context. As Battersby, Golledge, and Marsh (2006) found, understanding a concept does not always indicate being able to successfully use the concept. Although the present study demonstrated that enhanced knowledge about spatial concepts positively affected skills to incorporate these concepts into a lesson plan, it is worth examining how enhanced knowledge affects real classroom teaching.

Second, it is critical that research investigate what is the minimum level of experience (e.g., the amount of time or the amount of coursework in the domain of geography) and deliberate practice (e.g., focused practice to improve pedagogical content knowledge) for a preservice teacher to become capable of teaching spatial thinking through geography. This study only found that the development of skills needs much more time and practice. It did not provide much information about the specific amount of experiences and types of practice needed to actually become skillful. Further research to specifically examine the development of expertise in teaching spatial thinking will provide more insights into the design of both preservice and inservice teacher education.

Third, it would be desirable to examine the construct validity of the instruments developed and used in this study: the spatial concepts test and the teaching spatial thinking disposition survey. Although the content validity of these instruments were ensured by expert review processes, it is important to see how well each of the instruments actually distinguishes between the high performers and the low performers in terms of their teaching practices related to spatial thinking. For example, in order for the teaching spatial thinking disposition survey to be a really useful measure of teacher dispositions toward spatial thinking, it must be observable that high scorers tend to incorporate spatial thinking into the classroom more than do the low scorers. Such research may be conducted from a mixed-method approach where the disposition scores measured by the survey are compared with classroom observation results.

Lastly, it is important that research examine how spatially informed teachers make a difference in the development of students' spatial thinking skills. The ultimate purpose of this study was to foster a spatially literate populace although the focus was on preparing teachers to achieve the goal. It would also be worthwhile investigating as a next step how students' enhanced geographic and spatial thinking skills contribute to their development of inquiry and problem solving skills and to their understandings of contemporary issues in the globalized world. These research topics can be pursued effectively in partnership with classroom teachers and P-16 students.

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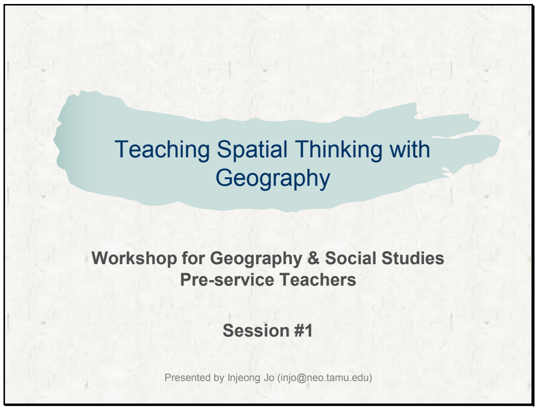
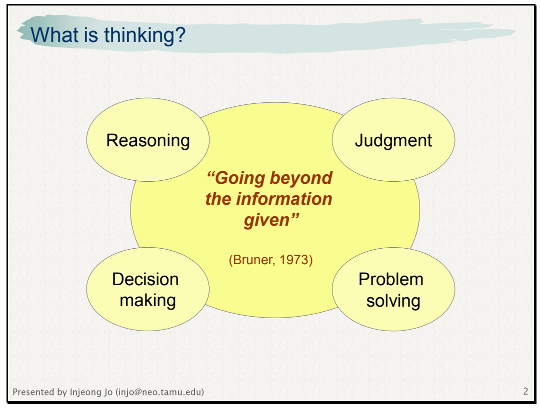
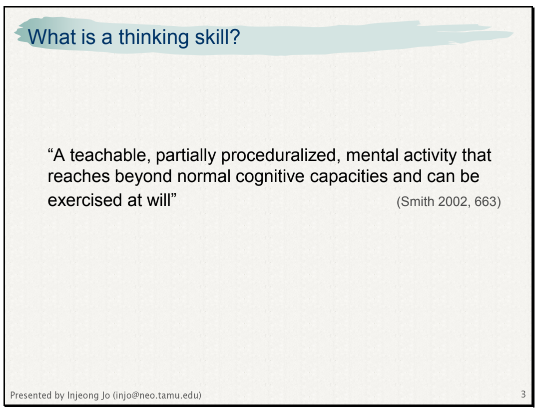
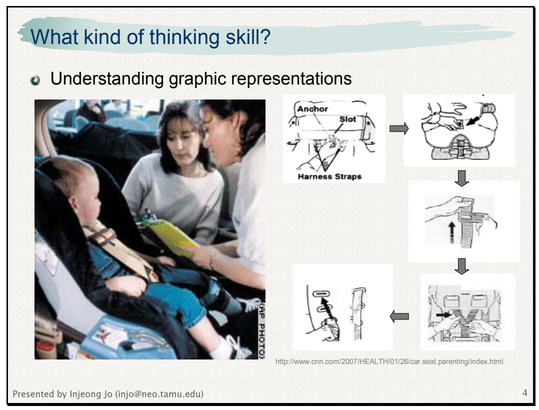
APPENDIX A

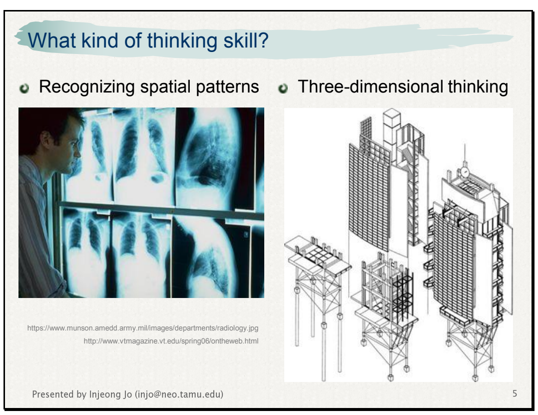
MATERIALS FOR SESSION #1

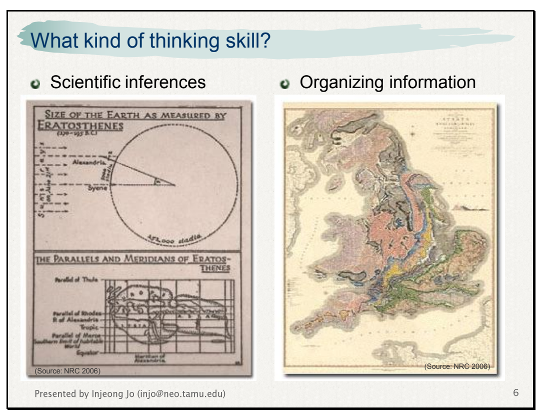

Teaching Spatial Thinking with Geography
Workshop for Geography & Social Studies Pre-service Teachers
Session #1
Presented by Injeong Jo (injo@neo.tamu.edu)


What is thinking?
Reasoning
Judgment
"Going beyond the information given"
(Bruner, 1973)
Decision making
Problem solving
Presented by Injeong Jo (injo@neo.tamu.edu)
2


What is a thinking skill?
"A teachable, partially proceduralized, mental activity that reaches beyond normal cognitive capacities and can be exercised at will"
(Smith 2002, 663)
Presented by Injeong Jo (injo@neo.tamu.edu)
3


What kind of thinking skill?
Understanding graphic representations
(AP PHOTO)
Anchor
Slot
Harness Straps
http://www.cnn.com/2007/HEALTH/01/26/car.seat.parenting/index.html
Presented by Injeong Jo (injo@neo.tamu.edu)
4


What kind of thinking skill?
Recognizing spatial patterns
Three-dimensional thinking
https://www.munson.amedd.army.mil/images/departments/radiology.jpg
http://www.vtmagazine.vt.edu/spring06/ontheweb.html
Presented by Injeong Jo (injo@neo.tamu.edu)
5


What kind of thinking skill?
Scientific inferences
Organizing information
Size of the Earth as measured by Eratosthenes
The Parallels and Meridians of Eratosthenes
(Source: NRC 2006)
(Source: NRC 2006)
Presented by Injeong Jo (injo@neo.tamu.edu)
6

Spatial thinking is…

- "A collection of cognitive skills comprised of *knowing concepts of space, using tools of representation, and reasoning processes*" (NRC 2006, 12)
- Important for efficacy and success in everyday life, at work, and in science
- Neither innate nor a result of high intelligence
- Can (and should) be taught with appropriately designed materials and activities
- Up to now, unappreciated, unrecognized, and therefore uninstructed
- Domain-specific

Spatial thinking and geography

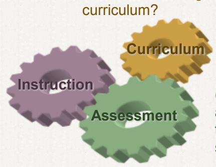
- The National Geography Standards *"Geography for Life" (1994)*
- Emphasis on the spatial perspective
- The World in Spatial Terms
- Standards
  1: How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information;
  2: How to use mental maps to organize information about people, places, and environments;
  3: How to analyze the spatial organization of people, places, and environments on Earth's surface

Teaching spatial thinking with geography

- Three questions…

(1) Is spatial thinking addressed in the geography curriculum?

(2) Do geography teachers incorporate spatial thinking into their teaching practices?

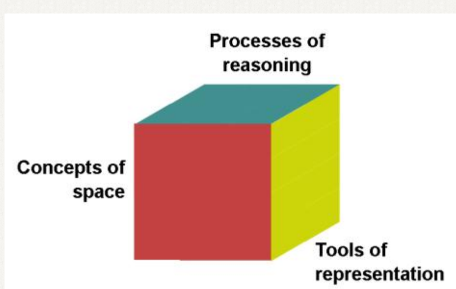


(3) Is the geographic assessment relevant to spatial thinking skills?

A taxonomy as a tool

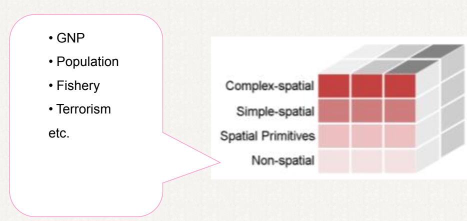
- To identify educational objectives
- To organize curricula
- To design lessons and assessments
- An educational taxonomy: *"a framework for classifying statements of what we expect or intend students to learn as a result of instruction"* (Krathwohl 2002)

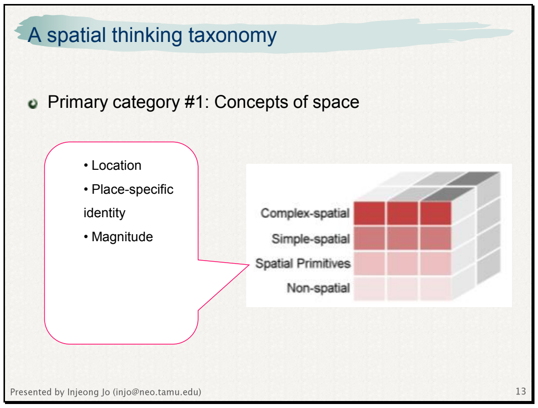
A spatial thinking taxonomy

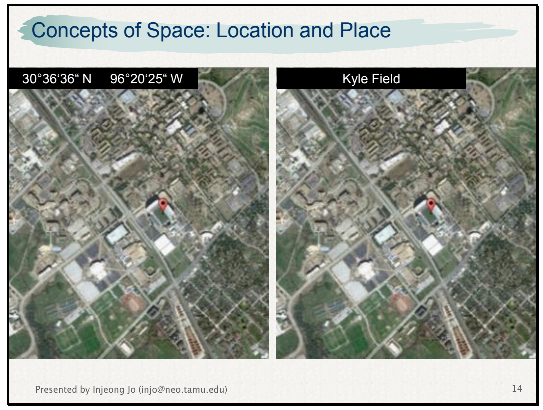


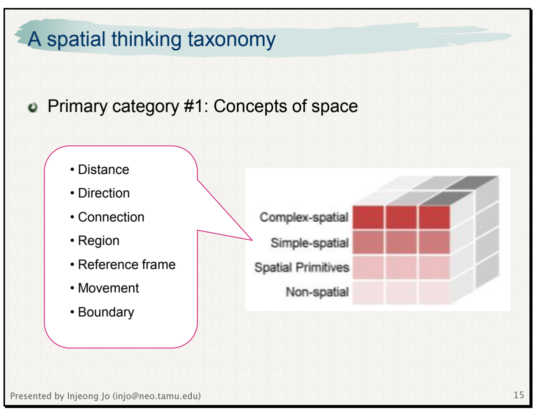
A spatial thinking taxonomy

- Primary category #1: Concepts of space




A spatial thinking taxonomy
Primary category #1: Concepts of space
• Location
• Place-specific identity
• Magnitude
Complex-spatial
Simple-spatial
Spatial Primitives
Non-spatial
Presented by Injeong Jo (injo@neo.tamu.edu)
13


Concepts of Space: Location and Place
30°36'36" N 96°20'25" W
Kyle Field
Presented by Injeong Jo (injo@neo.tamu.edu)
14


A spatial thinking taxonomy
Primary category #1: Concepts of space
• Distance
• Direction
• Connection
• Region
• Reference frame
• Movement
• Boundary
Complex-spatial
Simple-spatial
Spatial Primitives
Non-spatial
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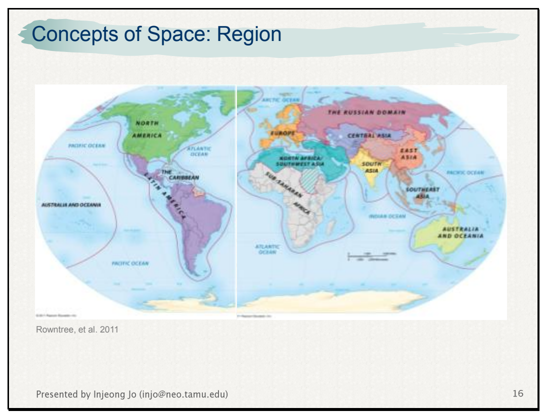
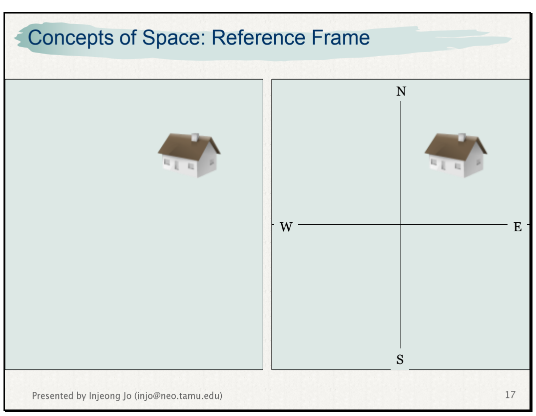
15


Concepts of Space: Region
NORTH AMERICA
THE RUSSIAN DOMAIN
EUROPE
CENTRAL ASIA
EAST ASIA
SOUTH ASIA
SOUTHEAST ASIA
AUSTRALIA AND OCEANIA
Rowntree, et al. 2011
Presented by Injeong Jo (injo@neo.tamu.edu)
16


Concepts of Space: Reference Frame
N
W
E
S
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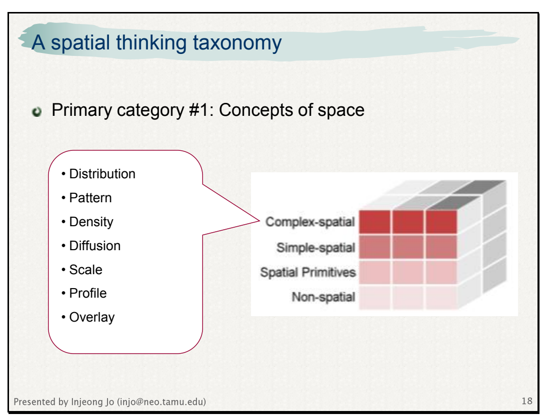
17


A spatial thinking taxonomy
Primary category #1: Concepts of space
• Distribution
• Pattern
• Density
• Diffusion
• Scale
• Profile
• Overlay
Complex-spatial
Simple-spatial
Spatial Primitives
Non-spatial
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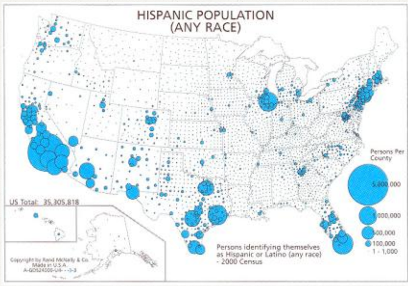
18

Concepts of Space: Distribution

- The arrangement of something across Earth's surface



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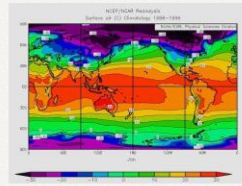
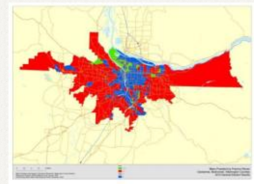
Concepts of Space: Pattern

- A combination of qualities, acts, tendencies, etc., forming a consistent or characteristic arrangement



http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/temperature/explaining_global_patterns_temperature.html



http://lindholmcompanyblog.com/?cat=17&paged=3

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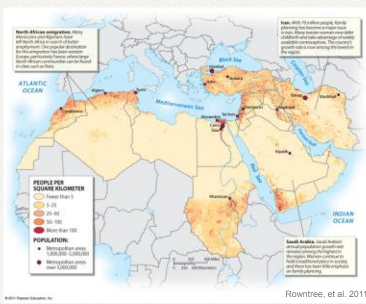
Concepts of Space: Density

- The number of inhabitants, dwellings, or the like, per unit area



Rowntree, et al. 2011

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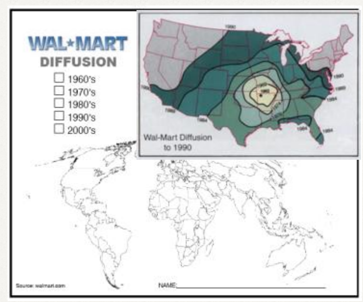
Concepts of Space: Diffusion

- The process of spread of a feature or trend from one place to another over time



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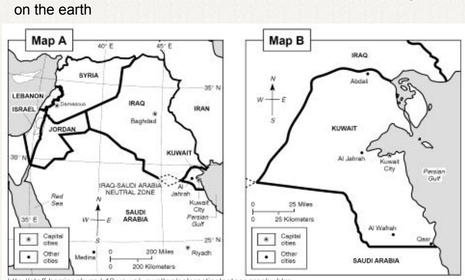
Concepts of Space: (Map) Scale

- The ratio between a distance on a map and the corresponding distance on the earth



http://staff.harrisonburg.k12.va.us/~cwalton/solpracticetestgeography.htm

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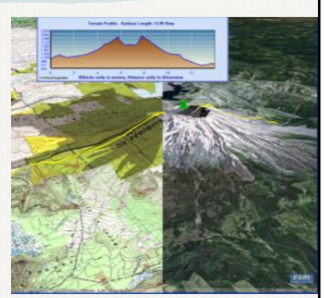
Concepts of Space: Profile

- An outline of an object, as a molding, formed on a vertical plane passes through the object at right angles to one of its principal horizontal dimensions



http://www.esri.com/news/arcwatch/0607/graphics/agexplorer2-lg.jpg

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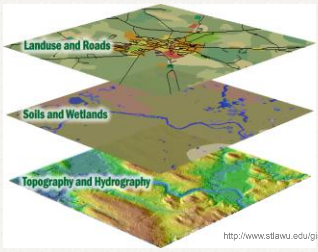
Concepts of Space: Overlay

- A spatial operation in which two or more maps or layers are superimposed for the purpose of showing the relationships between features that occupy the same geographic space



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A spatial thinking taxonomy

- Primary category #2: Tools of representation

- Map
- Diagram
- Graph
- Chart
- Satellite images

etc.

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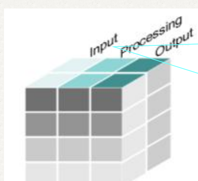
A spatial thinking taxonomy

- Primary category #3: Processes of reasoning



- Define
- List
- Label
- Recognize
- Name
- Match
- Count

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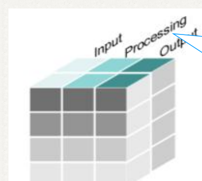
A spatial thinking taxonomy

- Primary category #3: Processes of reasoning



- Explain
- Compare
- Contrast
- Summarize
- Classify
- Infer
- Analyze

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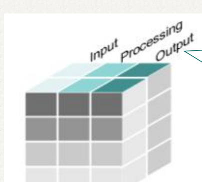
A spatial thinking taxonomy

- Primary category #3: Processes of reasoning



- Evaluate
- Judge
- Generalize
- Hypothesize
- Predict
- Create
- Build a model

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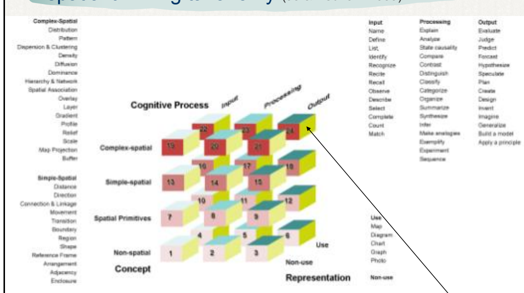
A spatial thinking taxonomy (Jo & Bednarz 2009)



An example objective: *The student creates a map of population density*

Activity

- Analysis of learning objectives using Spatial Thinking Taxonomy

Discussion

- Applications of the taxonomy to teaching practices
  - To identify educational objectives
  - To organize curricula
  - To design lessons and assessments

Spatial thinking taxonomy as a tool

- To design spatial thinking **lessons**
  - Lesson objectives
  - Teaching and learning procedures and materials
- To design spatial thinking **assessments**
  - Concepts
  - Tools of representation
  - Cognitive processes

Writing a reflective journal

- Three most important things
- New knowledge learned
- Skills developed
- Changes in attitude, willingness, or dispositions

APPENDIX B

WORKSHEET FOR SESSION #2

Session #2: Geography Lesson Video Analysis

Individual task

I. What kind of geographic questions are asked in the class?

II. Which geographic area (place, region, etc.) is of interest in the class?

III. Teaching and learning activity

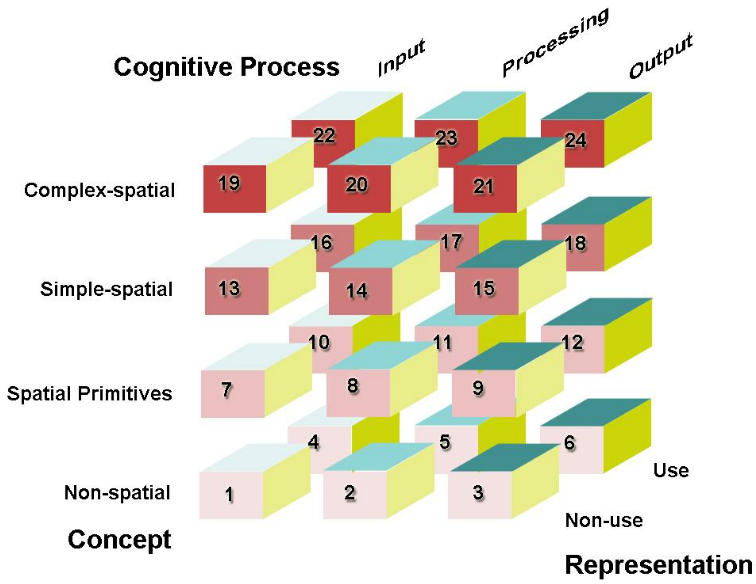
1. What kinds of concepts are discussed throughout the lesson?

2. What kinds of tools of representation are used for students' learning?

3. What kinds of cognitive processes do the students practice during the class?

Group discussion

I. Evaluating spatiality of the lesson using Spatial Thinking Taxonomy



III. Ideas for improvement to address spatial thinking skills more explicitly?

APPENDIX C

WORKSHEET FOR SESSION #3

Session #3: Geography Question Analysis

You will be given 6 examples of geography test questions. Examine each question carefully and analyze it in terms of the three components of spatial thinking addressed. Locate each question on the Spatial Thinking Taxonomy.

Question #	Concepts	Tools of representation	Processes of reasoning	Cell #
	________________________ Non | Primitive | Simple | Complex	___________ Non-use | Use	____________________ Input | Processing | Output	
	________________________ Non | Primitive | Simple | Complex	___________ Non-use | Use	____________________ Input | Processing | Output	
	________________________ Non | Primitive | Simple | Complex	___________ Non-use | Use	____________________ Input | Processing | Output	
	________________________ Non | Primitive | Simple | Complex	___________ Non-use | Use	____________________ Input | Processing | Output	
	________________________ Non | Primitive | Simple | Complex	___________ Non-use | Use	____________________ Input | Processing | Output	
	________________________ Non | Primitive | Simple | Complex	___________ Non-use | Use	____________________ Input | Processing | Output	

APPENDIX D

SPATIAL CONCEPTS TEST (POST-TEST)

SPATIAL CONCEPTS TEST

Research ID # ________________

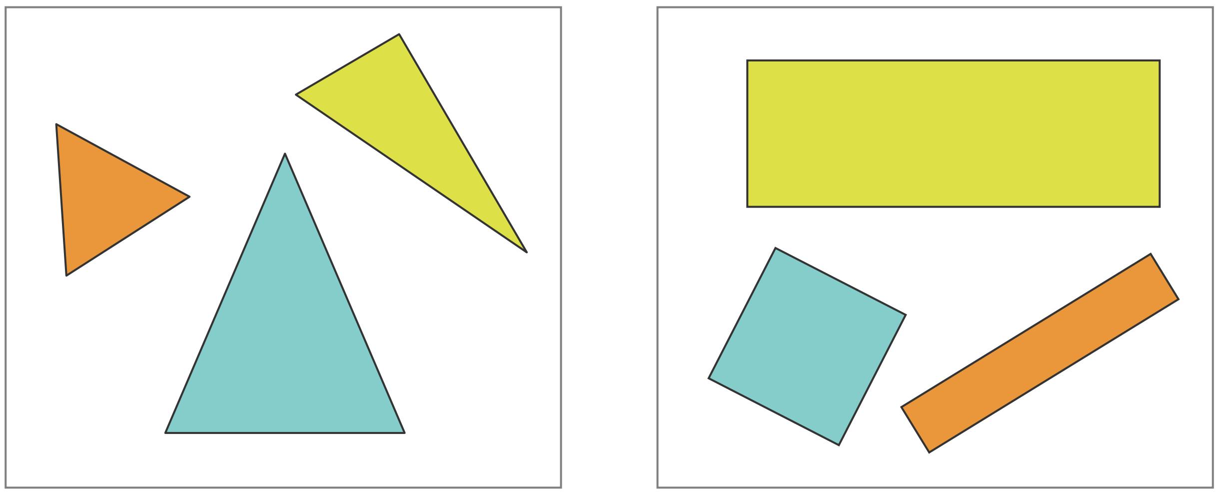
Date ________________

Note: The test consists of two parts. Each part has a practice item at the beginning. The instructor will go over the practice items with you in order to make sure that you fully understand how to solve the problems. You will be given 12 minutes to complete the test.

Part I

[Practice Item] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two images.

* Color	* Shape	* Size



[Practice Item] Provide AT LEAST ONE rationale for your selection.

Left-hand image is a collection of triangles while right-hand image is a collection of rectangles.

The concept distinguishing triangles from rectangles (or vise versa) is "shape".

[1-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay

[1-2] Provide AT LEAST ONE rationale for your selection.

[2-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay

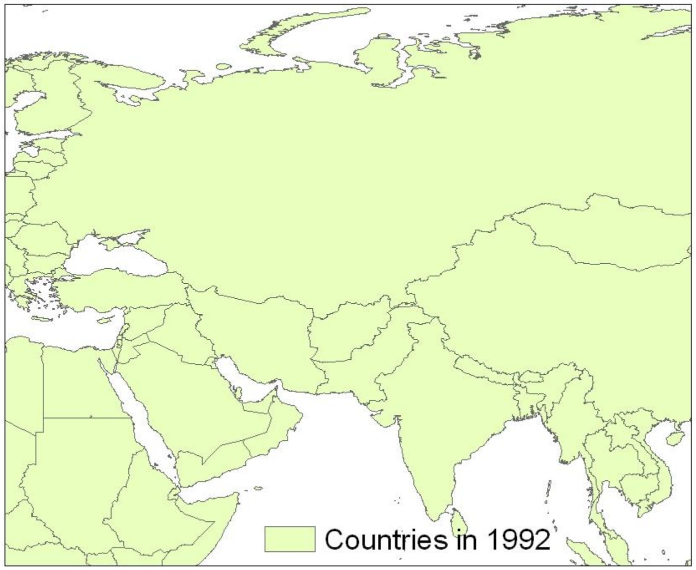
[2-2] Provide AT LEAST ONE rationale for your selection.

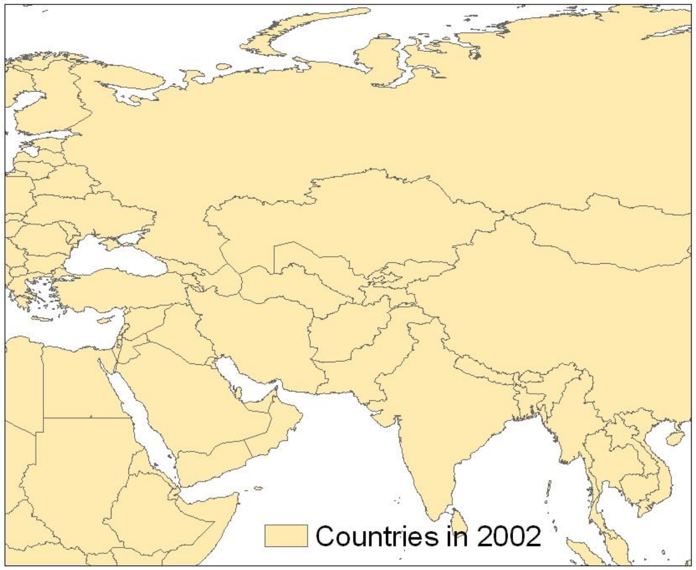
____

____

[3-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay





[3-2] Provide AT LEAST ONE rationale for your selection.

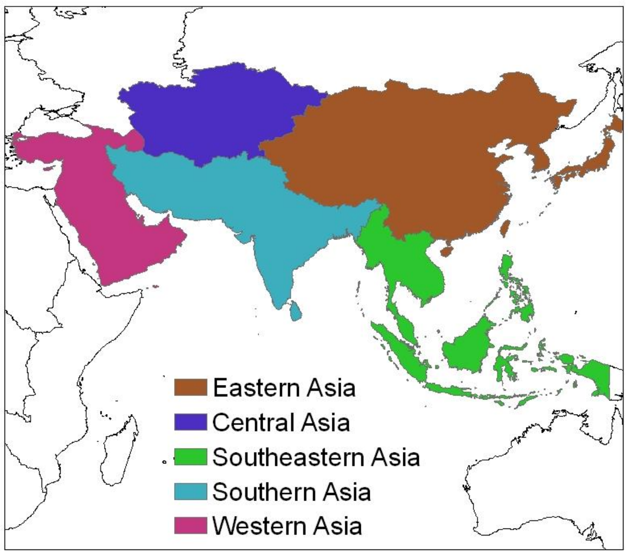
[4-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay

[4-2] Provide AT LEAST ONE rationale for your selection.

[5-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

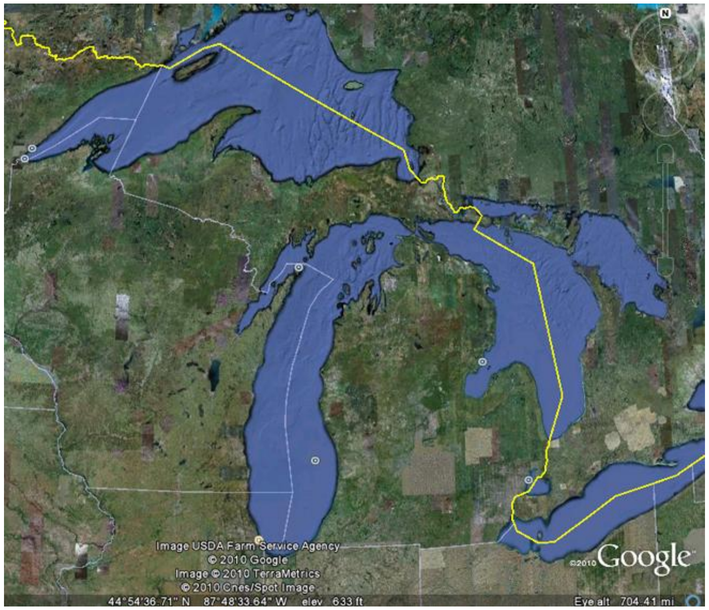
• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay



[5-2] Provide AT LEAST ONE rationale for your selection.

[6-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

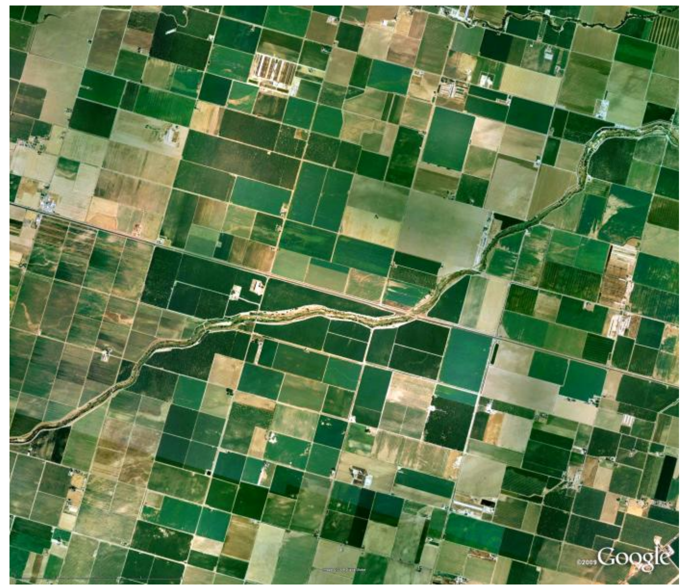
• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay



[6-2] Provide AT LEAST ONE rationale for your selection.

[7-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

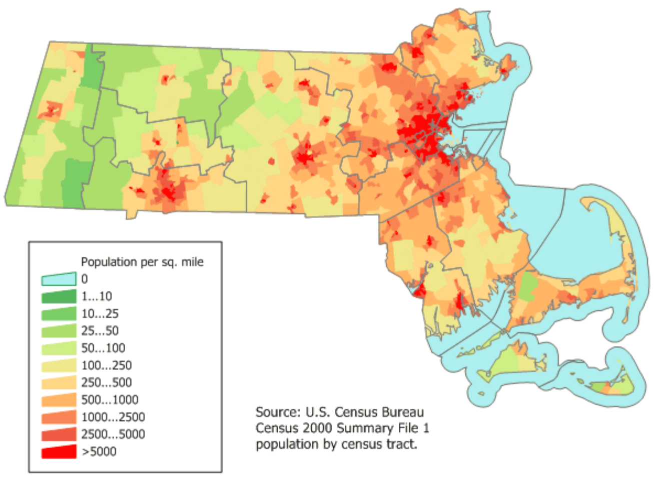
• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay

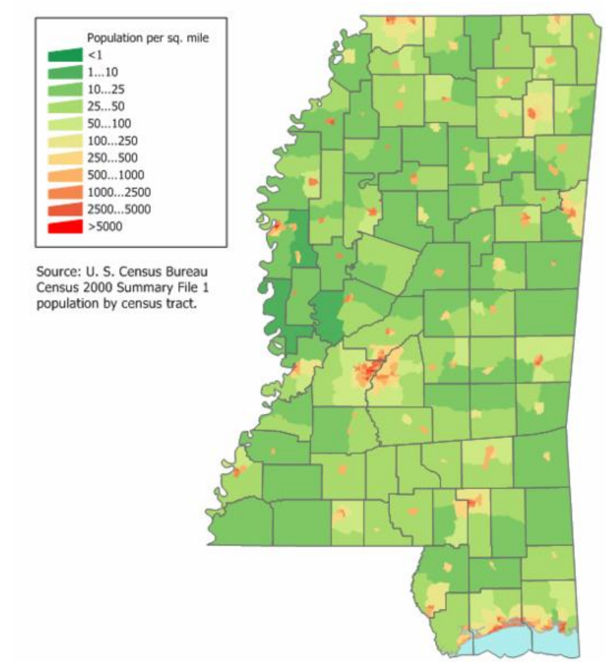


[7-2] Provide AT LEAST ONE rationale for your selection.

[8-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay

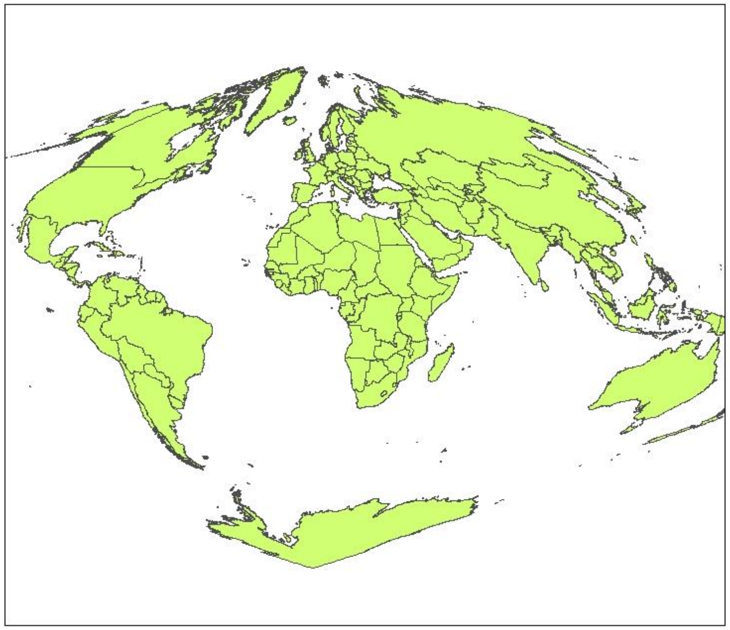


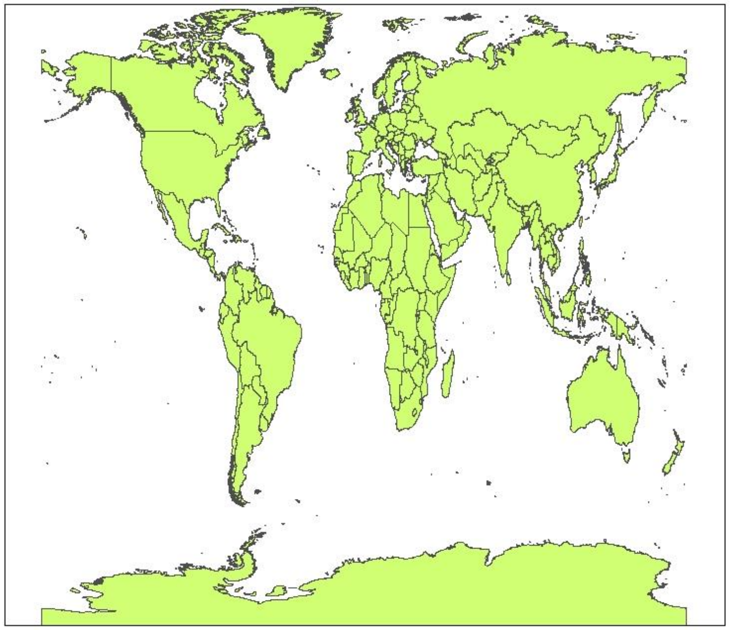


[8-2] Provide AT LEAST ONE rationale for your selection.

[9-1] Select ONE concept (circle on it) that BEST represents the DIFFERENCE between the two maps.

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay



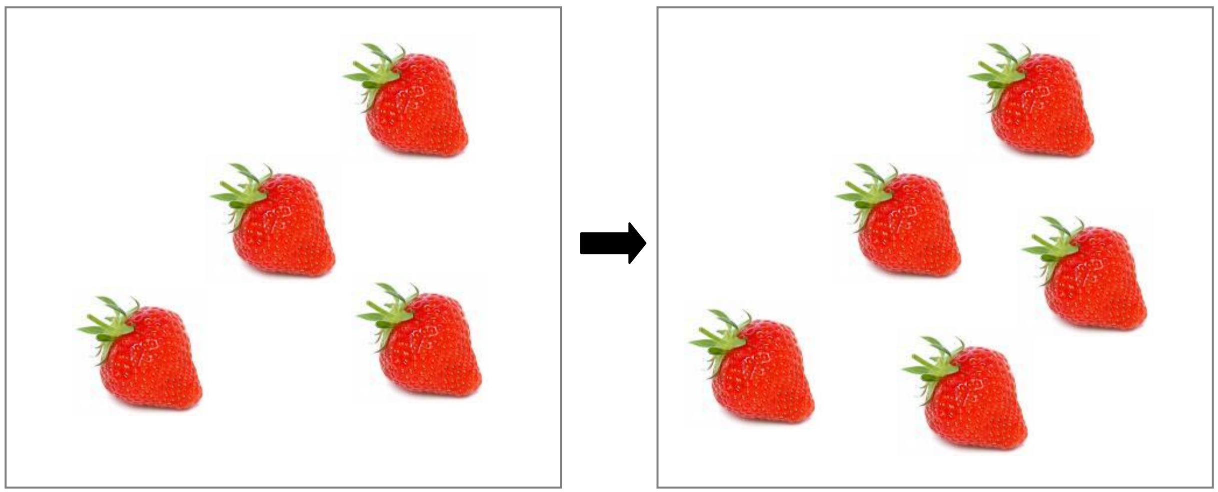


[9-2] Provide AT LEAST ONE rationale for your selection.

Part II

[Practice Item] Select ONE concept (circle on it) that BEST describes the PROCESS (or SEQUENCE).

• Addition	• Subtraction	• Division



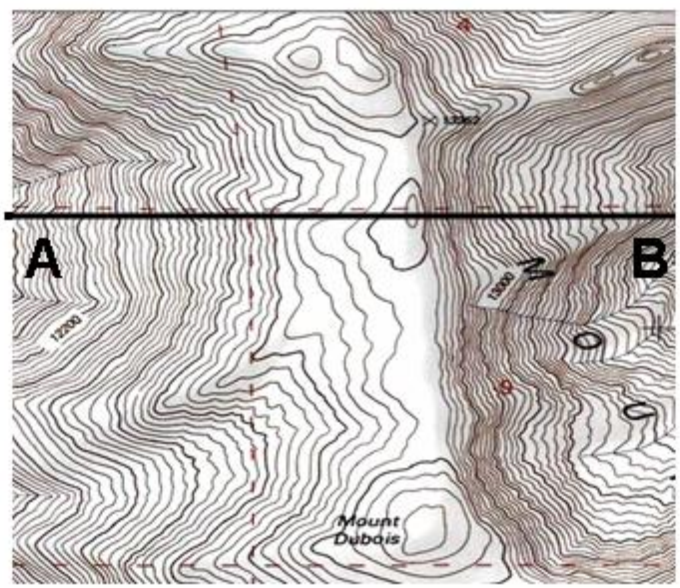
[Practice Item] Provide AT LEAST ONE rationale for your selection.

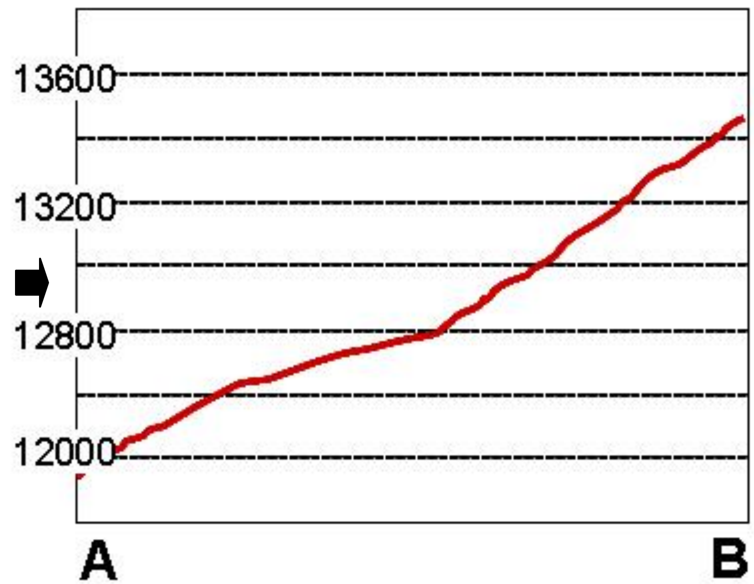
The number of strawberries was 4 and increased to 5 later on.

The process that best describes this process is addition.

[10-1] Select ONE concept (circle on it) that BEST describes the PROCESS (or SEQUENCE).

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay

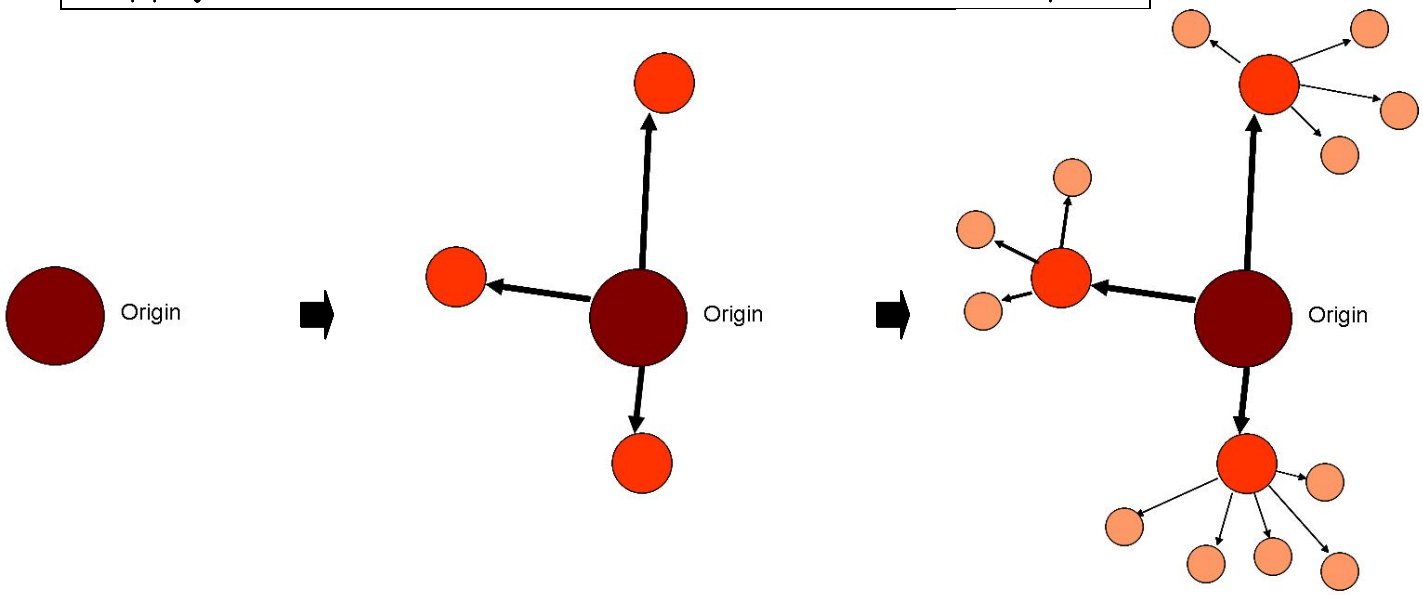




[10-2] Provide AT LEAST ONE rationale for your selection.

[11-1] Select ONE concept (circle on it) that BEST describes the PROCESS (or SEQUENCE).

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay

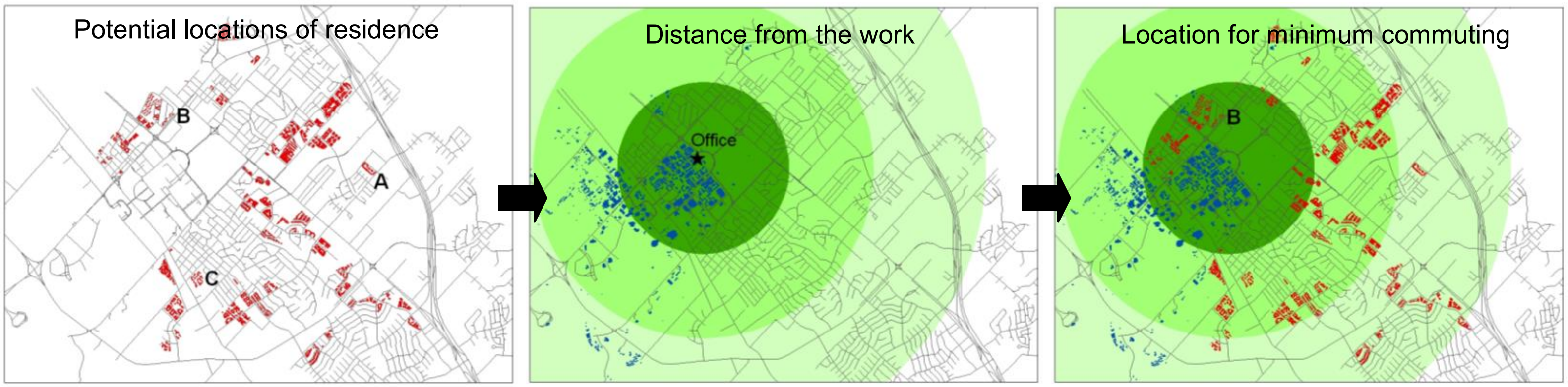


Places where Technology A is adopted   Places where Technology A is adopted   Places where Technology A is adopted

[11-2] Provide AT LEAST ONE rationale for your selection.

[12-1] Select ONE concept (circle on it) that BEST describes the PROCESS (or SEQUENCE).

• Pattern	• Scale	• Buffer	• Profile	• Density
• Distance	• Region	• Location	• Boundary	• Diffusion
• Map projection		• Reference frame		• Overlay



[12-2] Provide AT LEAST ONE rationale for your selection.

APPENDIX E

MINI LESSON PLAN TEMPLATE

Lesson Plan

Research ID		Date	

Topic	Settlement Patterns and Ways of Life in Canada

Objectives	1. I expect students to know concepts of:	
	1)	2)
	3)	4)
	5)	6)
	7)	8)
	9)	10)
	2. I expect students to be able to:	
	1)	
	2)	
	3)	

Step-by-step lesson procedures (teacher & student activities)	

Step-by-step lesson procedures (teacher & student activities)	

Assessment	Q1.
	Q2.
	Q3.

APPENDIX F

TEACHING SPATIAL THINKING DISPOSITION SURVEY

Disposition Toward Teaching Spatial Thinking Survey

Research ID #		Date	

	Strongly disagree	Disagree	Agree	Strongly agree
1. I believe that all students can learn.	1	2	3	4
2. I believe that thinking skills can be taught.	1	2	3	4
3. I believe that thinking skills should be taught.	1	2	3	4
4. My highest priority goal will be developing students' thinking skills.	1	2	3	4
5. I will feel satisfied when students remember exactly what they've learned.	1	2	3	4
6. I will frequently ask challenging questions and/or tasks.	1	2	3	4
7. I will like to show students how I think through a problem rather than only the final answer.	1	2	3	4
8. I will almost always ask students to provide explanations and reasons to support their answers.	1	2	3	4
9. I believe that geography is a mere collection of information.	1	2	3	4
10. I believe that geography has much to do with rote memorization of isolated facts.	1	2	3	4
11. I believe that geography has much to do with asking questions and solving problems.	1	2	3	4
12. I believe that geography is the study of spatial aspects of human existence.	1	2	3	4
13. I believe that understanding spatial patterns and processes is essential in learning geography.	1	2	3	4
14. I believe that the study and practice of geography require the use of geographic representations, tools, and technologies.	1	2	3	4
15. I believe that knowing and being able to use spatial concepts are essential in learning geography.	1	2	3	4
16. I believe that spatial thinking is an essential part of learning geography.	1	2	3	4
17. I believe that spatial thinking is powerful.	1	2	3	4
18. I believe that spatial thinking is integral to everyday life.	1	2	3	4
19. I believe that spatial thinking is a skill that is innate.	1	2	3	4
20. I believe that spatial thinking skills can be learned by everyone.	1	2	3	4
21. I believe that spatial thinking skills should be learned by everyone.	1	2	3	4
22. I believe that expertise in spatial thinking draws on spatial skills that are a particular domain of knowledge.	1	2	3	4
23. I believe that time and practice to develop expertise in spatial thinking within the school system is worthwhile.	1	2	3	4
24. I will explicitly teach concepts of location, place, and region.	1	2	3	4
25. I will explicitly teach concepts of spatial pattern, scale, density, and spatial diffusion.	1	2	3	4
26. I believe that spatial representations, such as maps, diagrams, and graphs help students in learning and problem solving.	1	2	3	4
27. I believe that students can readily interpret maps, diagrams, and graphs without a guided practice.	1	2	3	4
28. I believe that teaching students how to reason from maps, diagrams, and graphs is important.	1	2	3	4
29. I believe that having students construct their own maps, diagrams, and graphs is important.	1	2	3	4
30. I will use a variety of spatial representations including maps, diagrams, and graphs in my future class.	1	2	3	4
31. I will use spatial representations such as maps, diagrams, and graphs to convey a variety of kinds of thinking.	1	2	3	4
32. I believe that using and creating tools of representations, such as maps, diagrams, and graphs are essential for spatial thinking.	1	2	3	4

VITA

Name:	Injeong Jo
Address:	Department of Geography Texas A&M University College Station, TX 77843-3147
Email Address:	injeongjo@yahoo.com
Education:	B.A., Geography Education, Seoul National University, 1999 M.S., Geography, Texas A&M University, 2007 Ph.D., Geography, Texas A&M University, 2011 Post-doctoral Fellow, Curriculum and Instruction, University of Texas – Arlington, 2011
Research Interest:	Geography Education, Spatial Thinking Education, Teacher Education, Geospatial Technologies, Curriculum Development, and Assessment Development