The Effects of an Inquiry-Based Earth Science Course on the Spatial Thinking of Pre-Service Elementary Teacher Education Students

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THE EFFECTS OF AN INQUIRY-BASED EARTH SCIENCE COURSE ON
THE SPATIAL THINKING OF PRE-SERVICE ELEMENTARY
TEACHER EDUCATION STUDENTS

by

Kevin Douglas Weakley

A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Doctor of Philosophy
Mallinson Institute for Science Education
Advisor: Dr. Joseph P. Stoltman

Western Michigan University
Kalamazoo, Michigan
May 2010
THE EFFECTS OF AN INQUIRY-BASED EARTH SCIENCE COURSE ON THE SPATIAL THINKING OF PRE-SERVICE ELEMENTARY TEACHER EDUCATION STUDENTS

Kevin Douglas Weakley, Ph.D.
Western Michigan University, 2010

This study examined the effectiveness of two geography courses at improving student spatial thinking skills. Spatial thinking is an important cognitive skill in the sciences and everyday life. A taxonomy of spatial thinking was constructed by Gersmehl (2008) in geography education which included core modes assessed in this study: comparison, region, transition, analogy, pattern, and association. Two additional modes related to space over time, change and movement, were also assessed. The central research question in this study is: What are the effects of a pre-service teacher education earth science content course (Geography 1900) that is conceptually designed and inquiry-based on the spatial thinking of university students compared to the Geography 1020 course that follows a lecture format with an atlas study component? The six sub-questions to this central question were: 1) What spatial thinking modes are embedded in the Geography 1900 course based on the Gersmehl (2008) classification of modes of spatial thinking? 2) What modes of spatial thinking do pre-service elementary education students exhibit prior to instruction in Geography 1900 and 1020? 3) What changes occur in spatial thinking and spatial skills as a result of enrolling in and completing a conceptually based, inquiry course (Geography 1900) that has embedded clearly
identifiable spatial tasks based on Gersmehl’s classification? 4) What are the effects of Geography 1900 on the modes of spatial thinking that students apply at the completion of the course? 5) What modes of spatial thinking do students transfer from the classroom to the outdoors as they move about campus? 6) Are there differences in spatial thinking between the Geography 1900 population and the Geography 1020 comparison sample of students that received a different course treatment?

The research used a mixed methods approach with both quantitative and qualitative information. Statistically significant changes were observed in the use of spatial constructs and concepts by students in each of the course treatments that were compared. Students were also observed to apply spatial modes outside the classroom that represented the spatial thinking within the new context of the university environment as they observed and described the landscape.
ACKNOWLEDGMENTS

My deepest gratitude is extended to my Ph.D. advisor, Dr. Joseph Stoltman. His constant, scholarly advice and positive encouragement throughout this entire journey is greatly appreciated. As a faculty member at Western Michigan University since 1971, Dr. Stoltman's academic accomplishments and successes in geography education are numerous. He is truly an inspirational professor and advisor. I am very fortunate and thankful to have been mentored by Dr. Stoltman during these several years.

I also greatly appreciate the scholarly advice, suggestions, and positive encouragement of my Ph.D. committee members, Dr. Kathleen Baker and Dr. Heather Petcovic. I am very grateful for the encouragement and advice of the Mallinson Institute for Science Education Director, Dr. William Cobern. Remembering a conversation Dr. Cobern and I had several years ago about the nature of the Ph.D. program in Science Education at WMU, I realized my passion to complete my Ph.D. in this exceptional program. I am thankful for the encouragement of the faculty, staff, and graduate student colleagues in the Mallinson Institute for Science Education.

My sincere thanks are extended to the former Chair of the Geography Department, Dr. David Dickason, for his role in hiring me as an Instructor of Geography at Western Michigan University during 2002-2005. It was during these years that I developed a fondness for WMU. I am thankful for Dr. Dickason's encouragement in my entrance into the Doctoral program of the Mallinson Institute for Science Education.
I am thankful for Dr. Robert Ruhf’s assistance for his validating and collaboration in determining that the Geography 1900 syllabus activities have embedded modes of spatial thinking. I also want to thank graduate student colleagues Caitlin Callahan and Jeffrey Barney for their assistance as co-observers of the Geography 1900 syllabus activities.

I want to thank the following professors, colleagues, and special friends for their encouragement: Dr. Chansheng He, Dr. Hitoshi Hirano, Dr. David Rudge, Dr. Robert Ruhf, George Akom, Fang Huang, Robert Kagumba, Matthew Ludwig, Chaiphat Plybour, Brandy Skjold, Stephen Podewell, Matt Siebert, Steve Still, and Mei Li.

I am very grateful for the encouragement and prayers of my Pastors in the United Methodist Church, especially Rev. Dr. Harold Davidson in Columbus, Ohio.

I want to express my very sincere thankfulness to my family in central Ohio. In honor of my parents, Douglas & Constance Weakley, I am very grateful for their encouragement, unconditional love, and support in my quest to accomplish this goal. I am grateful for my brothers’ encouragement along with their wives: Kelly & Lyndsie, Kyle & Sunday, and Kent & Emily Weakley. I extend my loving appreciation and thankfulness for my grandparents’ unconditional love and encouragement: H. Kelly in memoriam & Mary Conklin, and Armond & Ruth Pauline Weakley in memoriam. I am thankful for my great-grandmother’s unconditional love and encouragement throughout my educational endeavors, Calista Kelly Guss, in memoriam. For the encouragement of all my extended
Acknowledgments—Continued

family relatives, especially my Uncle Dean Conklin, I am deeply grateful.

Most importantly, I want to thank God. During the difficult times and trials in this Ph.D. journey, my faith in God’s strength, love, and grace has sustained me.

With God, all things are possible.

Kevin Douglas Weakley
DEDICATION

Dedicated to the Enduring Memory of Henry Kelly Conklin (1923-2007)
An Inspirational Grandfather and Strong Supporter of Education
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CHAPTER I

PROBLEM STATEMENT

Description of Research Problem

Introduction to the Research

Many of the ideas and questions that led to the current research were initiated by the National Research Council’s comprehensive report on spatial thinking (National Research Council, 2006). As well as a thorough review of current spatial thinking research in the geosciences, it also serves as a benchmark from which to measure future research on this topic (NRC, 2006). The National Research Council publication suggests that spatial thinking serves three purposes and functions. The first function conveys the appearance of and relationships among objects, largely those on Earth’s surface. The second is an analytic function which enables an understanding of the relational structure of objects, or the ways that one or more objects on Earth’s surface may affect other objects. Third, the report delves into the importance of a differential function in the spatial arrangement of objects. Spatial orientation and arrangement are the important aspects of these functions (NRC, 2006).

An important outcome of the attention to spatial thinking has become collectively referred to a spatial literacy, or the ability of individuals to frame problems in spatial terms. The development of spatial literacy is hypothesized to be dependent on the
formation and interpretation of spatial representations and transformations between and among objects and patterns. For example, route-planning is a form of spatial literacy and entails using distance, type of path, number of terms, and streets or highways (NRC, 2006). The NRC report (2006) places considerable emphasis on Geographic Information Systems (GIS) as a means to implement spatial thinking and develop spatial literacy. GIS applies innovative visualizations and images that can help students with the application of spatial concepts.

Spatial thinking is a regular and important skill people use every day. Its importance is reinforced in that “People, natural objects, human-made objects, and human-made structures exist somewhere in space, and the interactions of people and things must be understood in terms of locations, distances, directions, shapes, and patterns” (National Research Council, 2006, p. 5). Spatial thinking is used widely in problem solving contexts “by managing, transforming, and analyzing data, especially complex and large data sets, and by communicating the results of those processes to one’s self and to others” (National Research Council, 2006, p. 5). These examples include mental object rotations, navigation tasks, visualization, and map analysis. Many of these tasks are important aspects of earth science education. The National Research Council (2006) argued that spatial thinking is important in the sciences, technology, and their applications in everyday life. Spatial thinking is viewed as synonymous with spatial cognition and additional research is needed on this topic and its relationship to education. Gersmehl’s (2008) theoretical framework formed the basis for the current study.
Background to the Research

Several aspects of spatial thinking are identified by the National Research Council (2006). They wrote that spatial thinking is the broad term used to describe people’s ability to process spatial information. Spatial ability is also related to people’s ability to solve spatial problems and tasks. Often, instruments used to measure spatial ability are pencil-and-paper tasks or presented on a computer. Table 1 presents Spatial Terminology.

Table 1: Spatial Thinking Terminology

<table>
<thead>
<tr>
<th>Spatial Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Thinking</td>
<td>A collection of cognitive skills including three elements:</td>
</tr>
<tr>
<td></td>
<td>- Concepts of space, tools of representation, and reasoning in the</td>
</tr>
<tr>
<td></td>
<td>form of a measurement (NRC, 2006)</td>
</tr>
<tr>
<td>Spatial Ability</td>
<td>Links these three: space, representation, and reasoning in the form</td>
</tr>
<tr>
<td></td>
<td>of a measurement (NRC, 2006)</td>
</tr>
<tr>
<td>Spatial Cognition</td>
<td>The thought processes involved in spatial thinking (NRC, 2006)</td>
</tr>
<tr>
<td>Modes of Spatial</td>
<td>Gersmehl’s contribution to spatial thinking is represented by modes that</td>
</tr>
<tr>
<td>Thinking</td>
<td>were determined through an extensive literature review. They include:</td>
</tr>
<tr>
<td></td>
<td>- comparison, pattern, aura, region, hierarchy, transition, analogy,</td>
</tr>
<tr>
<td></td>
<td>association as well as spatio-temporal modes that include change,</td>
</tr>
<tr>
<td></td>
<td>movement, and diffusion (Gersmehl, 2008)</td>
</tr>
</tbody>
</table>

There is a dearth of substantive research in assessing college-aged pre-service teacher elementary education students’ ability to think spatially. Research has examined other students’ ability to think spatially, especially in younger ages.

The significance of spatial thinking is an important component of educational assessment. The Geography Framework for the 1994 and 2001 National Assessment of
Educational Progress provide considerable evidence of the importance of spatial thinking. Gersmehl (2006) further argued that spatial thinking such as spatial-pattern analysis is a sophisticated activity that is transferable to numerous other cognitive tasks. Modes of spatial thinking skills have been identified by Gersmehl (2008) and numerous other researchers and philosophers have examined the topic as exemplified by the substantial bibliographies that are available (Black, 2005; Bunch & Lloyd, 2002; Golledge, Marsh & Battersby, 2008; Lee, 2005; & Linn & Peterson, 1985).

The aspects of spatial thinking that will be identified in this study are associated with the thinking processes students use as they work through spatial tasks. Gersmehl (2008) suggested that spatial cognition is thinking about locations, conditions, and connections. As scientists learn more about the brain, the similarities of spatial cognition and spatial thinking skills become more apparent. The spatial thinking skills are specifically those related to modes of spatial thinking established by Gersmehl (2008). Spatial cognition is an important aspect in psychological research. In the brain, there are regions use specific tasks. These tasks can include verbal, movement, and spatial cognition. The development of one’s spatial cognition in this region of the brain provides explanation for how people use skills to process spatial tasks.

The National Research Council (NRC) (2006) report on spatial thinking suggested a need for greater research since not very much that is definitive is known about the process and its importance to the general population as they navigate through the environment. Navigating through an environment requires students to use spatial thinking skills. This is one aspect of spatial thinking. Research informs us that spatial thinking is, in part, affected by schooling as well as other experiences. The current research study is
examining: a) factors that may influence spatial thinking among pre-service teacher education students; b) provide important insights about how spatial thinking is applied; c) the connection between the use of spatial thinking by teachers that may be extended to spatial thinking experiences for their students. As mentioned earlier, research has been completed with young children, but little has focused on the initial enrollment of college-aged students who are selecting a career path in education that will place them in the classroom with young students. The current research will examine what is important in the spatial thinking of students at college age when they obtain their pre-service professional education, and how it may inform and enhance their role as science educators.

The NRC (2006) suggested that researchers seek an answer to the question “How can one learn to become a better spatial thinker?” The present research will address the question: Are the experiences being provided to pre-service elementary science teachers making them better spatial thinkers? The NRC (2006) suggested that spatial thinking is a learned skill and should be taught and practiced in all grades, K – 16.

Spatial Thinking in Biology, Chemistry and Physics

The case for spatial thinking in the sciences of biology, chemistry and physics is well documented in the literature of educational and psychological research. Research has shown that the study of the cell in biology can be enhanced through learning with visual models and various representations (Wu & Shah, 2004). Although the visual models and various representations are different from the spatial navigation examples which are included in my study, all are relevant because they represent instruments of measurement
for spatial thinking. Research by Huk (2006) suggested that the implementation of 3D models in chemistry learning is helpful for students in developing mental models. Huk (2006) concluded that students with high spatial ability benefit from 3D models since they are capable of a more complete cognitive process. The research suggested that the educational value of three-dimensional models depends on students with high spatial ability. Students of low spatial ability became overloaded cognitively when using the 3D visual models and were less successful in comprehending the content. Future research was suggested to concentrate on mental models as they are represented and constructed by students with low spatial ability (Huk, 2006).

Spatial visualization is also required in multi-disciplinary sciences. "Chemistry is a visual science" and Wu and Shah (2004, p. 465) suggested that some visualization tools are effective in helping students overcome conceptual errors in chemistry. Principles such as providing multiple representations and promoting the transformation between 2D and 3D representations are among the five principles suggested for effective chemistry learning.

Spatial visualization is an important skill in solving kinematics problems in physics (Kozhevnikov, Motes, & Hegarty, 2007). Kozhevnikov, Motes, and Hegarty (2007) suggested that students with high spatial ability may enhance conceptual knowledge of physics principles. Problems included principles of velocity in moving projectiles and prediction of directional movement. The transformations from one frame of reference to another represented another example of spatial tasks utilized in the Kozhevnikov (2007) study that emphasized the importance of spatial ability.
Golledge, Marsh, and Battersby (2008) argued that all persons can benefit from effectively taught and presented geospatial concepts. Students, teachers, and society in general can develop an appreciation of thinking spatially. Five concept levels were described by Golledge, Marsh, and Battersby (2008) beginning with a set of spatial primitives. The primitives include the spatial concepts: identify location, magnitude, and space-time. These primitives are commonly used in earth science courses. College students also use the primitives to extend their spatial thinking to higher level concepts such as interpolation and projection in earth science/geography courses. This suggests that all spatial tasks are not equal in terms of the level of ability. Certain spatial tasks challenge one's ability to identify very simplified examples such as locating features on a map. These spatial primitives are the most basic concepts of spatial thinking according to Golledge, Marsh, and Battersby (2008). Higher geospatial concepts occur when connections and comparisons between locations are formulated by the person.

The Case for Spatial Thinking in the Earth Science Classroom

Researchers recognize that enormous variability exists in students' spatial ability, often recognized in geography education through map reading skills (Kastens, 2001). These students are generally adolescents and secondary education students. Some students encounter difficulty with maps and the spatial representations incorporated in their design and presentation of information (Ishikawa & Kastens, 2005). According to Orion and Ault, Jr. (2007), students' spatial ability can be improved through instruction and application. They suggested three contributions that might help with the improvement of student spatial thinking: inquiry-based learning, using an outdoor
learning environment for the construction of concrete models of a natural system, and using knowledge integration activities.

Rationale for the Research

Because little research exists on the study of undergraduates performing spatial tasks, the topic of the current research will use an understudied group relative to the phenomenon of spatial thinking research (Gersmehl & Gersmehl, 2007). The current study will contribute to the spatial thinking research by examining the learning and application of spatial thinking skills among pre-service teacher education students at the undergraduate level.

The purpose of this study will be to identify course work experiences that may affect spatial thinking abilities and applications in pre-service teacher education students. Earth science education includes the sciences of geography, geology, and geoscience; this incorporates the sciences related to the earth in terms of its physical structure and relationship with the atmosphere. Earth science education is comprised of physical geography without the components of cultural and regional geography. The earth sciences require spatial thinking as an important cognitive skill in problem solving and visualization.

The research on spatial thinking in geography education is important for two major reasons. First, elementary pre-service teachers interact with children who are in the formative stages of their thought processes. It is important that such teachers are cognizant of the opportunities for recognizing and using spatial thinking with young children. The interaction between elementary teachers and their students is not the focus
of this study. The importance of assessing pre-service elementary teacher education students’ ability to think spatially is important since classroom experiences are assumed to be an important gateway to spatial skills. Informed teachers regarding spatial thinking is considered a key part of the equation by the researcher.

While the importance of spatial thinking as part of education is widely recognized, there has been relatively little research focused on its importance to those who plan to become elementary school science teachers. Second, substantial numbers of universities offer courses similar to the earth science for elementary teachers that will be the treatment in the proposed research. The research and its conclusions will serve as a model to guide spatial thinking and inquiry-based geography education curriculum. Spatial thinking and visualization is a fundamental aspect of all science; consequently, spatial thinking is important in science teaching. Recent reviews of the science education literature reveal that spatial thinking occurs in math, chemistry, biology, physics, and earth science, the latter which is the focus of this dissertation research.

Questions and Hypotheses Guiding the Current Research

Creswell (1998) suggested that drafting an overview research questions with several sub-questions is effective and follows a tradition of inquiry. The factors affecting spatial thinking are central to the research questions and are interrelated with the following questions. The present research problem consists of six sub-questions and one central question.
Central Question: What are the effects of a pre-service teacher education earth science content course (Geography 1900) that is conceptually designed and inquiry-based on the spatial thinking of university students?

The central question was further developed into six subquestions:

1. What spatial thinking modes are embedded in the Geography 1900 course based on the Gersmehl (2008) classification of modes of spatial thinking?

2. What modes of spatial thinking do pre-service elementary education students exhibit prior to instruction in Geography 1900?

3. What changes occur in spatial thinking and spatial skills as a result of enrolling in and completing a conceptually based, inquiry course (Geography 1900) that has embedded clearly identifiable spatial tasks based on Gersmehl’s classification (2008)?

4. What are the effects of Geography 1900 on the modes of spatial thinking that students apply at the completion of the course?

5. What modes of spatial thinking do students transfer from the classroom to the outdoors as they move about campus?

6. Are there differences in spatial thinking between the Geography 1900 population and a comparison sample of students that receives a different treatment?

Formulation of hypotheses is an important component of research in science education. Thus, following the clarification of the questions to be examined in the study, the following formal research hypotheses were put forward as a means to guide the collection of and analysis of the data. The hypotheses, which are discussed in detail within Chapter IV, are as follows:
1. Geography 1900 has clearly identifiable modes of spatial thinking embedded within the earth science content.

2. Students apply specific modes of spatial thinking before instruction as measured by the Spatial Thinking Test.

3. Modes of spatial thinking by students in Geography 1900 will significantly improve as a result of their completion of the course.

4. Geography 1900 will have a positive effect on the spatial thinking of a majority of students.

5. Students apply modes of spatial thinking in their activities outside the classroom as indicated during a spatial walk.

6. Students completing Geography 1900 will demonstrate greater improvements in spatial thinking compared to students in the Geography 1020 comparison group.

This study will concentrate on examining the theoretical underpinnings for spatial thinking as a cognitive process that results in an enhanced means for students to complete and reflect on spatial tasks. The research will rely on grounded theory in which the observational and interview work performed by the students will allow new discoveries and empirical evidence to emerge and produce new knowledge (Glaser & Strauss, 1967). Transcripts of interview dialogue and observation discussions will be a central aspect in the analysis, as will pre and post test data collection and analysis. Both quantitative and qualitative methods are important to the current the research questions.

**Significance of the Research**

Spatial thinking is recognized as both a geospatial navigational and a problem solving tool in the earth sciences because earth science requires identifying shapes, sizes,
connections, map analysis, and multi-dimensional transformations of space on Earth (National Research Council, 2006). The NRC report suggested that student spatial thinking can be improved through classroom instruction and training. The spatial tasks performed by undergraduate students in the pre-service teacher education curriculum at Western Michigan University will enable the researcher to assess factors affecting spatial thinking and gain insight into teaching strategies designed to promote spatial ability.

Most of the pre-service teacher education students who are enrolled in science education courses will eventually teach elementary school students. It is the hope that these future elementary grade teachers will employ spatial learning in their own lesson plans. In this regard, elementary students will also benefit from learning spatially in everyday life. The National Research Council (2006) suggested that learning spatially is important at all levels, K-16. By assessing and training future educators to think and learn spatially, educators will have a start at may model those applications in their own classrooms and incorporate strategies that are appropriate to the ages of their students. The current research is an early step in validating the effectiveness of science content and inquiry-based instruction on the spatial learning in the earth science classroom.
CHAPTER II

LITERATURE REVIEW

Introduction

This literature review encompasses studies and research related to spatial thinking in a topical order. The review begins with the early studies, specifically Piaget’s emphasis on this cognitive skill. The development and importance of visual-spatial thinking is a critical aspect in this review. This cognitive skill should be taught in the classroom. The benefit of spatial thinking is apparent in the use of problem-solving and visualization in the earth sciences. All sciences including biology, chemistry, and physics require students to use spatial thinking; the earth sciences require the use of spatial thinking to a greater extent since the content is spatially arranged relative to Earth.

The topical order begins with Piaget’s influence in the 1960s and moves into other areas of spatial thinking including studies of gender differences. Throughout these decades, gender differences are noted and assessed, especially in the 1980s. Spatial ability is also clearly defined in the literature review. In numerous studies, students were subjected to spatial tests to determine their ability to think spatially by demonstrating the physical manipulation of items or completing tasks that were spatial. Many of these tasks involved pencil and paper, while other examples involved students in another setting. These studies and the types of tasks are outlined in this literature review, as is the spatial terminology. This terminology is all incorporated into spatial thinking as a whole.
Subsections represent topical categories. These are outlined in the following sections and reveal different aspects of spatial thinking.

1950s-1960s: Studies of Children’s Conceptions of Space

Early research on childhood development and visual-spatial thinking was guided by Piaget. The model Piaget used was reflected as a behavioral model of developmental stages and the capacity for higher order thinking. The research suggested that higher order thinking develops concurrently with development of visual-spatial thinking (Piaget & Inhelder, 1956).

One of the earliest works related to spatial thinking was the Piaget and Inhelder (1956) book entitled: “The Child’s Conception of Space”. The first known test of spatial ability in the book was the water-level task. A subject was shown a bottle sitting on its base at a variable angle relative to a table top. The subject was asked to draw a line on a paper sketch of the bottle in its upright position to indicate where the water surface would lie within the bottle. In another example, the children were shown a tilted water glass held at a 45 degree angle and asked to draw a line to show how the liquid would look if it were about half full. Children at very early ages had difficulty, while at older ages children recognized that changes in position relative to the sides of the container make no difference in the amount of water in the vessel. Piaget and Inhelder’s (1956) research paved the way for further studies in the aspects of spatial learning for children, adolescents, and eventually adults. Tests of spatial ability are now more detailed, encompassing a great number of spatial skills, although much of the current experimental work with spatial thinking may be traced back to Piaget’s studies.
Studies of mental transformations by children were addressed in further research by Piaget and Inhelder (1956). The researchers proposed that early childhood imagery is reproductive in nature and that transformational reasoning with images occurs with developing mental operations. In further research of adult reasoning, Piaget and Inhelder (1956) suggested that large differences are present in transformational reasoning as evident by being able to mentally rotate objects. An example of the mental rotation of objects was the widely cited and replicated three mountain task used by Piaget (Piaget & Inhelder, 1956).

Studies on Differences in Spatial Thinking

A major focus of prior research has been devoted to differences between females and males on spatial thinking. The number of males included in the present research was not adequate to do a similar analysis, but the amount of attention devoted to the topic in the literature necessitates a discussion of research prior results. The concept of gender differences in spatial thinking was also examined. The advantage of males in spatial thinking has been documented based on several factors, including puberty and hormonal changes, and the rearing of boys with outdoor orientations as compared to girls. Maccoby and Jacklin (1974) determined that the male advantage in thinking spatially emerges in adolescence and is maintained throughout adulthood. Other studies suggest little differences between males and females on certain spatial tasks, particularly on the use of maps and map-learning tasks (Golledge et al., 1995).

McGee’s (1979) study on human spatial abilities is often cited in literature with the evidence that environmental, genetic, hormonal, and neurological differences are the
main factors in explaining differences in spatial abilities. McGee's (1979) article is benchmark research on the variability of spatial ability person-to-person and among the genders. The results clearly suggest that many variables contribute to the ability of students to think spatially. The very fact that people live in locations from urban, suburban, and rural areas and that they are exposed to a wide range of influences and outside experiences have been more clearly demonstrated as affecting the development of spatial thinking.

Liben (1981) observed that males are encouraged to enroll in mathematical and science courses, whereas females often elect to take language-based courses. While research is not conclusive, there are suggestions that males and females may differ in their thinking as both the result of background experiences and perhaps hormonal changes during different periods of life.

Psychological studies further reveal that gender differences are observed in performing certain spatial tasks associated with maps. The research reported that males achieved higher scores in a variety of visual-spatial activities (Gilmartin & Patton, 1984). Map-use skills were also observed to be related to the level of student spatial ability. In their research, Gilmartin and Patton (1984) suggested that there is no different between male and females in map-use skills. The ability for a student to use spatial thinking in map use can be partly attributed to the educational and experiential background of the student. Although psychological research suggested that males outperform females in spatial tasks, geographers have noted that the difference may not be significant in a statistical or practical way. Roadmap reading and other map use skills may not readily translate into a significant difference between males and females. It is possible that
differences depend more on the geographical task than spatial ability when explaining the differences between males and females (Gilmartin & Patton, 1984).

Spatial thinking is an ability that underlies a person's predisposition to mentally perform rotations and other changes among objects in two and three dimensional space. Linn and Petersen (1985) developed a classification of three spatial abilities as part of their research. The three classes are: spatial perception, mental rotation, and spatial visualization. The Linn and Petersen (1985) research is a benchmark meta-analysis of others' research in spatial ability and gender differences. The authors suggested that males outperform females in mental rotations, but are quite similar in spatial perception and spatial visualization. The research suggested that explanations for sex differences involve early childhood experiences and biological and hormonal changes.

Bunch and Lloyd's research (2002) suggested also that biological and environmental variables may affect the spatial abilities of individuals. He concluded that spatial intelligence is related to inherent and learned spatial abilities, and is used and understood by individuals in different ways depending on particular contexts. However, despite the many research studies, there is not yet a set standard or research measurement that has been agreed upon by researchers to fully analyze individual spatial ability and whether differences between males and females may be the result of biological and/or environmental factors.

Bunch and Lloyd's (2002) research further noted that the different interactions and small differences among genes may result in notable differences in spatial abilities. Prenatal exposure to testosterone is one indicator in influencing the brain in its organization and lateralization. A person with high lateralization has most of the
resources for a particular function located in one or the other of the brain's hemisphere. If that is the case, Bunch and Lloyd (2002) suggested that the brain would need fewer connections to process and transfer information to the other hemisphere. Past research suggests that greater right-lateralized activations are the result of completion of spatial tasks (Galin, 1974; Schwartz, Davidson, & Maer, 1975; Babiloni et al., 2006).

Research literature identified by Bunch and Lloyd (2002) suggested that males may have increased spatial ability because of the hunter and gathering processes. This hypothesis has both anthropological and historical foundations. As males were more heavily involved in the navigation in unfamiliar environments, the evolutionary selection theory argues that modern man may be the beneficiary of those historical trends. Females may have been engaged in gathering in a local environment that is more familiar, and gained less contextual experience in mentally recording and reproducing spatial cues. The gatherer would also be able to identify specific landmarks from memory and recall the locations of food in distant places. These ancient trends in human evolution may be reflected in the modern scheme of navigation and route-planning by males and females, and thus explain the enhanced spatial ability of males to females on certain tasks. In this regard, earth science necessitates the study of locations and relationships among and between observed features of Earth.

Other theories also suggest environmental variables that may affect spatial thinking among individuals. The Right Shift Theory (RS) suggests greater use by females than males of the right hemisphere of the brain; this shift also shows that a larger portion of females may use the left hemisphere for verbal processing of information (Bunch & Lloyd, 2002). While Bunch and Lloyd (2002) reported that male and female genetics
were believed to be significant in spatial thinking, he also proposed that exposure to environmental and cultural variables are important. Research suggests the relationship of women who have both genetic potential and spatial experiences as being a positive factor in contributing to successful performances on spatial tasks.

Theories of spatial thinking suggest factors that seem to be influential in explaining differences between males and females. Genes, hormonal differences, and brain lateralization are biological differences that could be responsible for gender differences in spatial thinking. Past research has clearly defined gender differences on some spatial tasks in the field of geography, especially those that entail map reading and interpretation (Gilmartin & Patton, 1984). Self, Gopal, Golledge, and Fenstermaker (1992) suggested that males and females differ in task performance on certain spatial problems related to navigation outside in the environment.

Spatial Visualization

It is also being verified by the research that spatial visualization and spatial thinking are closely related. Spatial visualization is the process by which people mentally manipulate, rotate, or reposition an object that is two- or three-dimensional into a new or transformed orientation. Spatial orientation involves viewing patterns from different angles or perspectives. Among the attributes that are used to classify spatial visualization is that of spatial relations, which is a major component of the present research. Spatial relations include the attributes of estimating and reproducing distances, lengths, and other linkages through space (Golledge, et. al, 1995). Spatial visualization, spatial thinking, and
spatial relations are components of spatial intelligence as has been defined by Gardner (1983).

The study of spatial visualization and thinking has been bridged to developmental psychology. One theory of cognition was developed by Vygotsky (1978) which focused on the relationship between visualization and communication. His theory of cognition emphasized the aspects of culture, social behavior, and historical contexts. Because communication and spatial visualization are widely used in science classroom observations directly as well as through images, Vygotsky's (1978) research provided opportunities to transfer those theories to research in science teaching and student learning.

Visual-spatial exercises have been demonstrated to be important in the development of student visual-spatial self-awareness through performing specific spatial tasks. Scientific creativity has also been attributed to the development of spatial thinking when using imagery (Mathewson, 1999). Visual-spatial cognition has a fundamental role in science, and this is also an important component of science teaching. Spatial relationships between the earth and sun represent an important aspect of spatial thinking in the earth sciences.

Visualization and spatial thinking are also critical in learning chemistry. Wu and Shah (1999) advocated greater implementation of spatial thinking skills in the teaching of chemistry. The ability by students to view objects or figures in various representations and relationships is important in chemistry education. Additionally, the nature of chemistry is often taught with the presentation of dynamic and interactive features. The transformation of objects and figures from a two-dimensional to three-dimensional
perspective is important to the comprehension of molecules and their behavior. Finally, a reduction of cognitive load is possible when explicit and integrating information are provided with several different cognitive options for students (Wu & Shah, 1999).

Wiley (2003) suggested that visually rich presentations benefit the learner’s grasp of spatial concepts. Such learning may include animated images, virtual simulations, pictures and video in order to give the learner a real-world experience. Much of the stimuli that people are exposed to in current times is visual. Learners who are shown a visually rich presentation can apply the information to construct their own visualizations or transfer them to new contexts (Wiley, 2003). Because of differences in spatial ability, some students may require more and different types of visualizations. The overall effect of increased visualization for those students who have low spatial ability may result in an increase in comprehension and conceptualization. Other supportive instructional elements, such as the written text and graphic visuals, are a valuable aspect for differentiating instruction based on multiple intelligences (Gardner, 1983).

Research in visual analytics is providing important information on the role of spatial thinking in geosciences (Andrienko, G., Andrienko, N., Jankowski, Kaim, Kraak, Maceachren, & Wrobel, 2007). The research suggests that spatial visualization is a key factor in the development of spatial literacy. The research reports that “visualization is an effective way to provide material for human’s analysis and reasoning...[and] for supporting the involvement of humans in problem-solving” (p. 585).

Animations were researched for their effects on visualization (Andrienko et al., 2007). The research revealed that animations are an important aspect of visualization and
are a positive aspect of earth science education. This research revealed that students can use animations as an effective resource in learning and problem solving.

**Drawings and Representations of Space**

There is research evidence that central to spatial intelligence are “the capacities to perceive the visual world accurately, to perform transformations and modifications upon one’s initial perceptions, and be able to re-create aspects of one’s visual experience, even in the absence of relevant physical stimuli” (McCormack, 1988, p. 5). McCormack (1988) suggested that visual/spatial thinking is multidimensional with several interrelated abilities including perception, memory, logic, and creativity. This ability is an essential component of the elementary school science experience. In the elementary classroom, students may draw to record their observations. Drawing is an important aspect of an observation. The drawings may represent rotations of objects in space and even the spatially interrelated images of the components of biological specimens (McCormack, 1988). Children’s spatial thinking and visualization are also incorporated into school learning experiences. The ability for students to think spatially requires the appropriate training of the elementary school teachers to include spatial thinking skills in their instruction. McCormack (1988) suggested several activities that can be used in the elementary school classroom. These include making paper patterns representing shapes of blocks, paper-folding, predicting and drawing shapes of different objects and relating these to biological specimens, and observing objects from multiple perspectives. There are other opportunities using floor maps of the community where spatial components are organized to reflect reality in the student’s eye. Visual/spatial thinking is important in
everyday life as the perception and awareness of our surroundings emerges into spatial concepts and patterns. It is essential for students to develop spatial thinking skills at an early age as they explore new conceptual meanings and spatial patterns.

The classroom is an important medium for learning spatial skills and the science classroom should enhance the opportunities for students to learn and experience spatial thinking activities. Students often are required to transform images between three-dimensional realities and two-dimensional pictures and images. In science, students are exposed to two and three-dimensional pictorials and images that can enhance their spatial thinking skills. Concepts of geography and other sciences including biology and chemistry use examples of images that require students to think spatially (McCormack, 1988).

Mental Maps

Spatial interaction includes distribution of goods, people, and information which is relevant to geography. The complex patterns observed on the surface of the earth develop within the observer as perceptions. Gould and White (1986) studied the ways in which ‘mental maps’ are related to various characteristics of the real world patterns. They observed that mental images are easier to construct when one is familiar with the location as opposed to an entirely different environment. In a city for instance, the knowledge of landmarks and routes are among the spatial elements from which mental images are constructed. Environmental or psychic stress may add an invisible mental topography to the perception of a place (Gould & White, 1986). The factors of relative location and accessibility are also important. Perception of place and the mental maps which are
formed through filtered information flows represent spatial thinking (Gould & White, 1986).

Spatial Orientation

Although spatial thinking is important in geography, spatial orientation skills appear to be linked in understanding mathematical problems. Results from Tartre (1990) suggested that skills such as estimating the approximate magnitude of a figure or mentally rotating the size and shape of a figure aids in solving problems within a spatial, visual framework. The relationship between mathematical learning and spatial thinking is related to specific tasks. The research suggests that spatial thinking has numerous applications in the realms of the sciences and mathematics.

Cognitive processes such as Piaget's classification involving imagery suggest that the learner constructs a mental image or a transformation. Other studies suggest that mental rotations and mental transformations are linked to neurological processes (Kosslyn & Koenig, 1992). Visual processing in the brain acquires information from the temporal cortex to parietal cortex of the brain (Kosslyn & Koenig, 1992). The research evidence suggests that linkages within the brain are important for students to think and learn spatially.

Because geography is a study of the relationships between people, places, and environments, mapping is an effective means of integrating these elements. The Geography Education Standards Project (1994) emphasized the world in spatial terms as the first standard. When students think in spatial terms, they will have the ability to describe and analyze the spatial organization of people, places, and environments. The
Geography Education Standards Project (1994) suggested that breaking patterns of spatial organization into the components of points, lines, areas, and volumes enhances spatial thinking. Instruments and resources used by scientists to acquire spatial data from maps, globes, and satellite images are dependent on spatial analysis and thinking. The Geography Education Standards Project (1994) recommended that students continue to have direct experience with a wide variety of geographic representations, such as maps, throughout K-12. Additionally, students should have the opportunity to become familiar with geographic information systems and mental mapping that is a mixture of objective knowledge and subjective perceptions. Mental mapping research suggests it is an effective application of spatial thinking. The National Geography Standard 2 proposes the use of mental maps to organize information, while Standard 3 introduces the analysis of spatial organization of people, places, and environments (Geography Education Standards Project, 1994).

The research by Golledge, Dougherty, and Bell (1995) on route determination suggested that a background in geography enhanced route planning. Golledge’s (1995) findings suggested that spatial configuration of routes was an important factor in the overall performance by research subjects on spatial tasks. Golledge, Marsh, and Battersby (2008) also argued that spatial primitives are the basis for comprehending relationships with route knowledge, navigation and wayfinding. Spatial primitives are the fundamentals of spatial skills.

When students experience the tools of spatial representation, such as maps symbols, areas, they seem to have greater success in spatial thinking. Questions regarding whether college-aged students are aware of their surroundings represents the world
around them represents an important research question. Static features in the environment are important in establishing the relationship between and among objects, such as buildings, intersections, etc. The relationship of two or more entities or relating an entity to a reference frame such as a map is associated with orientation, location, size, color, shape, and texture (National Research Council, 2006).

Gardner's Multiple Intelligences

Howard Gardner developed a theory of multiple intelligences that emphasized the many ways in which humans approach learning and apply skills to solve problems. Individuals, according to Gardner, have strengths in some types of intelligence and less capacity in others. The development of one type of intelligence will compensate for another to a degree in everyday life and intellectual tasks. Gardner's categories of intelligence, including linguistic, logical-mathematical, bodily-kinesthetic, musical, interpersonal, intrapersonal, naturalist, and spatial, have been reviewed, researched, and commented on by other scholars (Vardin, 2003).

According to Gardner (1983), who has written widely about multiple intelligences, the conceptualization of relevant spatial factors is very important in the sciences, and identified spatial intelligence in his research. Geography, as a science, requires patterns of thought involving connections and relationships among entities that are spatially distributed. Multiple intelligences emphasize the many characteristics in which humans solve problems. Such intelligences include linguistic, logical-mathematical, bodily-kinesthetic, musical, interpersonal, intrapersonal, naturalist, and
spatial intelligence. Spatial intelligence has implications in both geography and earth science.

Gardner did apply his theory of multiple intelligences to students’ learning in a 1995 journal article (Gardner, 1995). He stated that “all of us possess each of the intelligences, but no two individuals exhibit exactly the same profile of intellectual strengths and weaknesses. Each intelligence exhibits its own developmental trajectory” (p. 16). Spatial thinking as treated in the current research complements Gardner’s theories especially as it pertains to the preparation pre-service elementary education students who intend to become teachers. Experience with spatial thinking for pre-service elementary teacher education students is one means to highlight the role it will play in their work with elementary students.

Map Analysis and Spatial Thinking

Spatial analysis using maps to achieve cognitive proficiencies is important in the teaching of geography and earth sciences. Research initiatives pursued by geographers provide insight on the use of maps and analysis as visual displays (MacEachren, 1995). Visual-spatial thinking consists of “vision – the process of using the eyes to identify, locate, and orient ourselves in the world, and imagery – the formation, inspection, transformation, and maintenance of images in the ‘mind’s eye’ in the absence of a visual stimulus” (MacEachren, 1995, p. 34). Research has shown that students apply visualization skills and processes when solving map problems and viewing displays. Computer software programs are often used to display earth science, atmospheric and climate visuals and call upon special types of spatial thinking by the student. Computer
images readily display multiple-representations and dimensions of the earth and are expected as a mainstay within the 21st century earth science classroom. The development of spatial thinking and technological advancements in pedagogy are of major interest in the research community of geographers and cognitive psychologists.

Weather forecasting using spatial information and the patterns of atmospheric conditions on maps was researched by Ishikawa, Barnston, Kastens, Louchouarn, & Ropelewski (2005). In the study, students were asked to identify aspects of climate on a physical map. It was observed that they had difficulty assessing different aspects such as interpretations of three-dimensional patterns of climate forecasts. Weather forecasts on maps are complex due to the three-dimensional interpretations that are necessary using a two-dimensional map. Ishikawa et al. (2005) suggested that improvements in the design of maps, and digital maps provide the means to explore the three-dimensional aspects of the atmosphere. Interactive maps would also allow students to view multiple images at once with layered information that may be accessed through a menu of options. In this sense, the concept of spatial association (Gersmehl, 2008) may be introduced through both the information on the map as well as the manipulation on the map in order to visualize the information. The presentation of information on the map is important for visualization and interpretation by the viewer. The research suggests that learners benefit from complex maps, such as those with weather forecasts, if they are able to apply spatial thinking skills to interpretation tasks (Ishikawa et al., 2005).

Within education, applications of spatial thinking go beyond earth science classrooms. Spatial thinking is a cognitive skill useful in mathematical education. Spatial structuring entails the organization and construction of an object form or collection of
objects within mathematics (Battista, Clements, Arnoff, Batista, & Borrow, 1998). This type of spatial structuring features different levels of abstraction about the shapes and sizes of objects. Spatial structuring is a technique used as a means to assess the spatial ability among elementary aged students. The mental rotation of geometric shapes and objects is another example of assessing spatial ability. Battista et al. (1998) suggested that the structuring of two-dimensional and three-dimensional space is the foundation for geometric and spatial thinking. Rearrangement and orientation of features is evident in earth science problem solving that includes drawing, mapping, or visual imaging on a computer. In earth science, space is usually structured and organized using a coordinate system, such as latitude and longitude. Spatial thinking requires the learner to superimpose different shapes and patterns on the coordinate system in order to explain spatial relationships. Different components of spatial thinking have been revealed through research. Among them is one application of spatial thinking that entails identifying objects in relationship to the observer. Second, the language used to communicate spatial thinking allows people to determine the fundamental locational properties of objects. Third, the observer views objects based on their dimensions and geometric shape, but also the observer must also view the scale of objects and uses scalar relations between objects to arrive at a sense of spatial context (Monetello, 1999). A fourth consideration occurs when the location properties derived from the context allows the observer to apply correctly the concepts of boundaries, density, shape, pattern, and region.
Geography Education and Spatial Concepts

Golledge suggested that “in geography, knowledge of space represents the accumulation of facts about the spatial arrangements and interactions comprising human-environment-relations and recognition of fundamental concepts – i.e., the declarative base of geographic knowledge” (Golledge, 2002, p. 1). Thinking spatially and spatial reasoning are the foundations for assessing both past and new geographic data. The human-environment relationship and place-to-place conditions represent an important aspect of geographic knowledge and understanding. Golledge (2002) suggested that geographic knowledge serves two purposes: 1) to establish where geographic objects are located, and 2) to experience ways that those objects may be factored into decision-making and problem-solving. Geographic knowledge includes knowing about places and features and their spatial relationships, which is an important aspect of spatial thinking. Communicating this geographic knowledge through cartography and visualizations are important applications of spatial thinking in the classroom. The occurrence of spatial thinking among individuals, such as university students, may be assessed and analyzed in research studies. Student spatial abilities are important to learning geography and earth sciences content and should be investigated relative to problem-solving and everyday life activities.

The processes of spatial thinking and cognitive skills are also related to language. Carlson’s research (2003) proposed that spatial language serves as an important basis for investigating the extent to which such language influences other processes. Spatial terminologies are often with reference to objects and relationships that reference other
locations (Carlson, 2003). Little research has been completed that relates objects and spatial terms.

Dodick and Orion (2003) evaluated the cognitive skills necessary for students to complete tasks in geologic time. Geology, as an earth science, uses information and map analysis that are related to spatial thinking. The earth is complex in its physical features and processes from the depths of the earth to the interaction with the atmosphere. Both spatial and temporal skills are necessary when students are visualizing change across space through time. Three schemes of reasoning are proposed for the spatial-time continuum. They are transformation, temporal organization, and inter-stage linking. The transformation serves as a principle of change, such as the reconstruction of geological and biological processes, observed in fossil and depositional environments. The temporal organization is a scheme in which a sequence can be assessed in categories or stages such as superposition and rock layer strata. The inter-stage linkage scheme is a combination of actualism (whereby, the present is a key to the past) and scientific reasoning (Dodick & Orion, 2003).

Dodick and Orion (2003) examined the factors functioning when student’s ability to reconstruct geological systems that have changed and developed over time. A Temporal Spatial Test (TST) was used in this study. The students participating were in grades 7-12. Results of the research indicated that the students’ ability in spatial visualization affected their ability to order the strata (rock layers). The measurement instruments consisted of organizational puzzles and paper-and-pencil tests. The researchers rationalized that:
Indeed, the understanding of rates of change is a basic concept of all scientific disciplines both as a methodological problem (the measurements of rates) and as a philosophical problem (continuous vs. discrete rates of change). Thus, exposing students to this concept within the earth sciences gives them a better understanding of one of science’s universal concepts (Dodick & Orion, 2003, p. 436).

Dodick and Orion (2003) also noted that there had not been research within science education at that time on the relationship between change rates observed changes in geological features or data. The principles in earth science education, particularly in geology, require student comprehension in the dynamic processes of the earth including change throughout time. In order to conceptualize the processes of strata reconstruction throughout time, spatial visualization is an important element due to the observation that is necessary. The cognitive skills of solving earth science problems are clearly linked in spatial thinking.

Bednarz and Bednarz (2004) outlined the challenges for geography education within the spatial thinking context. As suggested by other researchers as well, the most important problem for geography education is the lack of theory-based research on which to build spatial thinking research (Bednarz, 2000; Bednarz & Bednarz, 2004). They have suggested that geographical information science has a close affinity to spatial thinking, and promises opportunities for theories to be developed and researched. Such an approach to research will benefit geography as well as other science disciplines that are engaged in the improvement of spatial learning. The applied elements of their research apply to students who are able to learn effectively through research and theory based instructional designs which implement and teach spatial thinking.
Gersmehl’s Framework for Spatial Thinking

The research completed on the modes of spatial thinking (Gersmehl & Gersmehl, 2006) serves as an excellent basis for the cognitive processes and terminology. Modes of spatial thinking evolved from Gersmehl’s (2006) analysis of an extensive literature on spatial thinking research from disciplines ranging from cognitive science to medicine.

Gersmehl extracted evidence from the literature that humans use eleven modes of spatial thinking. They are: 1) comparison: how are places similar or different?; 2) aura: what influence does a place have on nearby places?; 3) region: what nearby places are similar to this one?; 4) transition: how do things change between two places?; 5) analogy: what places have similar conditions?; 6) hierarchy: what larger area is this area inside?; 7) pattern: what distinctive arrangements can you see?; 8) association: are spatial patterns related (correlated)?; 9) change: how do conditions change through time?; 10) movement: does something change position through time?; 11) diffusion: how do things spread through time?

The modes of spatial thinking are key to this literature review and served as the basis for the methodology of this dissertation. It is based on the knowledge that certain parts of the brain are activated when completing a particular spatial thinking task or problem (Gersmehl & Gersmehl, 2006). The modes of spatial thinking are regularly used in the cognitive processes of problem solving and map analysis, since the map is a basic spatial image either on paper, electronically, or in one’s mind.

Gersmehl & Gersmehl (2006) initially suggested twelve modes of spatial thinking. They formed the basis for a series of teaching and learning projects he designed
that were used in classrooms with students. Observations were made of the classroom interactions, and data were collected. Of particular interest to the current researcher, the modes could be applied to the earth science/meteorology instructional assignment used Geography 1900. The course included inquiry lessons that engaged the students in examining spatial attributes and identifying spatial patterns with reference to the atmosphere and atmosphere-land surface interaction.

The research by Gersmehl and Gersmehl (2006) pointed out that different parts of the brain are used to perform various spatial tasks. The brain is complex and consists of specific regions with specific roles in cognition, based on evidence from brain-scan technology. The researchers have identified neurologically distinct centers where eight core modes of spatial thinking occur. The eight modes are: comparison, aura, region, hierarchy, analogy, transition, pattern, and association. These modes were verified through a critical analysis of literature and research review (Gersmehl & Gersmehl, 2006). The research evidence suggests that young children develop certain aspects of spatial thinking and as they progress into adolescence and adulthood, other areas of the brain related to spatial thinking develop to complement and connect neurologically with the earlier spatial thinking abilities.

Geography Education/Earth Science and Spatial Thinking Research

The establishment of a taxonomy of spatial thinking is viewed as an important goal in research. Contributions by Gersmehl and Gersmehl (2006) represent the juncture between basic and applied research. Much of the research studies they have synthesized provide positive indicators of brain patterns and functions associated with spatial
learning. The rational extension from basic research to curriculum planning and classroom instruction seems obvious. The cognitive skills and descriptions from the research literature seem to make sense when applied to lesson plans. The research indicates that children can and should learn fundamental aspects of spatial thinking at an early age, it is important that pre-service teacher education students who are preparing to teach young children are being taught these same skills.

Gershmel’s research examined several of the same concepts as did the research by Black (2005), but from different contexts. Black was interested in spatial misconceptions, whereas Gersmehl was interested in identifying the modes of spatial thinking that are applied in geography and subsequently in much of earth science instruction. Black (2005) observed spatial factors were often misconceived by students. For example, she based her argument on the process of mental rotation, or viewing objects from different locations and angles in relationship to some other object. Black (2005) concluded that the connection between the ability to determine angular size and the ability for disembedding patterns within aerial or satellite photographs were related. Furthermore, two-dimensional to three-dimensional conversions are frequently used in the earth sciences as students move from a flat map or diagram to a raised relief map or model.

Black (2005) concluded that certain conceptual problems present a special difficulty for students. These include understanding of scale and transforming two-dimensional diagrams to three-dimensional formats, both mechanically when using props and mentally when using verbal descriptions. The transformation of multi-dimensions is often taken for granted, but entails a complex set of skills that are derived from spatial thinking.
Tversky (2005) suggested that spatial reasoning is the basis for abstract knowledge and inference when using maps and mapping. Visuospatial aspects of the world can be captured by examining visual properties such as shape, texture, and references to distance and direction (Tversky, 2005). Her research suggested that graphics are an important element to organize and create schematic representations. The ability to transform and manipulate objects is a spatial skill applied in earth science where patterns, objects and movement are prevalent.

Measuring and Reporting Spatial Ability

Gramann, Muller, Eick, & Schonebeck (2005) investigated student approaches to performing spatial task from several points of reference. The students were presented with a diagram of a tunnel and were instructed to navigate through it following straight and curved routes. The groups of students using different strategies to address problems were placed in separate groups: turning and non-turning groups. The turners performed a spatial task by mentally rotating their frame of reference. The non-turners performed a spatial task by tracking the orientation with paper and pencil. It was hypothesized that individuals have different frames of reference when solving a spatial task or mental rotation. In that sense, some of the information about the tunnel was visible, while other information was inferred. The results of the study suggested that participants mentally visualize movement through a tunnel set a homing vector from the end position back to the origin. The establishment of a heading vector in the path was related to their frame of reference (Gramann et al., 2005). The researchers concluded that coexisting
representations are equally important in navigation (Gramann et al., 2005), which is consistent with the research by Golledge (2005).

Black's (2005) research was completed using non-science majors enrolled in the College of Natural and Applied Sciences at a midwestern public university. A twenty multiple choice questions test was given to students to identify Earth Science misconception and conceptual difficulties. All areas of earth science were represented. The Purdue Visualization of Rotations Test was also used. Testing students with geometrical objects and asking rotation questions is a frequently applied method of assessing spatial ability. Black (2005) observed positive correlations at a moderate level between scores on the test of Earth Science concept understanding and the scores of the three spatial ability tests.

Black's (2005) research suggested there is an important relationship between earth science conceptual understanding and spatial ability. The link between the earth sciences (physical geography, meteorology, and geology) and spatial thinking should be emphasized through instruction. He believed that earth science misconceptions could be reduced through the use of visualizations and multi-dimensional tasks.

Spatial thinking through journal writing has been researched by Hooey and Bailey (2005). They studied the effects of journal writing in learning geography and developing spatial thinking skills. The research (2005) was designed so students performed writing tasks in two separate sections. The first section was a written summary of an event that they had read, while the second section represented a personal opinion. The researchers argued that students should learn and develop skills at interpreting the distribution of physical and cultural phenomena at different scales, including the global scale. Their
research suggested that spatial thinking goals can be accomplished through written assignment that capitalize on interpreting and presenting spatial information in narrative, written formats. Students received preparation to apply critical thinking skills to assess and process spatial problems and issues. Spatial thinking and the application of spatial concepts in writing narratives may also complement development of a worldview perspective as a proposed goal in science education (Cobern, 1991).

Several researchers have proposed that the development of spatial thinking should begin early in the curriculum (Everett, 2005). The research is particularly relevant to the present research regarding the preparation of elementary teachers who will likely teach earth science as part of their self-contained classroom assignment. The research suggested that elementary educators should select appropriate activities to develop students’ ability to think spatially. Elementary students learn about patterns and shapes through pattern blocks. Tessellations are complex patterns used in mathematics that are used to develop and extend the spatial ability of elementary students. The ability to think spatially is not only important in the sciences, but in mathematics as well. The observation by Everett (2005) applies to the role of spatial thinking opportunities in the curriculum when he states: “By learning more about how children think and develop, we can create opportunities for students to develop to their fullest potential” (Everett, 2005, p. 30).

Recent research has provided additional evidence of the importance of spatial thinking in the geosciences (Hemler & Repine, 2006; Kastens & Ishikawa, 2006). Learning to think spatially is not only important for the students, but for teachers as well. Teachers should apply instructional methods that promote and develop spatial thinking
among their students. Kastens and Ishikawa (2006) argued that spatial thinking as a cognitive skill is useful in the geosciences. This cognitive skill is essential in problem solving and viewing aspects of the earth.

Battersby, Golledge, and Marsh (2006) suggested that spatial thinking and science are closely connected, especially considering the degree to which spatial representations are applied in the geosciences. Learning geography requires the use of distributions and relationships that are key elements.

Research suggests that not all students are able to successfully use and apply geospatial concepts that incorporate spatial thinking (Battersby et al., 2006). Furthermore, the research reveals that a distinct hierarchy of geospatial concepts were learned by various ages and grade levels. The research has demonstrated that higher-order geospatial concepts are more difficult and present a greater challenge for younger students (Battersby et al., 2006; Golledge, 2005). For example, using map overlays, an important aspect in spatial analyses, is a complex cognitive process for middle school students. Data from the research indicated that university students used overlays correctly. Approximately 95% of the high school students used them correctly. About fifty percent of middle school students used the overlays correctly.

The complexity issue is an important consideration in educational and learning applications. The map overlay problem is a task which required the association among spatial patterns. The map overlay represents more advanced spatial analysis, yet research suggests this concept may be too advanced for younger middle school students (Battersby, Golledge, & Marsh, 2006). Battersby et al. (2006) suggested using a cognitive
order so that students could focus on developmentally appropriate geospatial concepts and tasks.

Bodzin and Anastasio (2006) built the argument in their research that learning spatial concepts and data analysis skills are essential for Earth system science education using inquiry-based instructional methods. Their research also suggested that visualization is an essential component in the application of spatial thinking, either in interpreting and using graphics or in the development and production of graphic materials, such as reading remotely sensed images or producing maps from data sources.

Other Applications of Spatial Research

Spatial Ability and Science Teaching

Sanchez and Wiley (2007) studied undergraduate students at the University of Illinois at Chicago and concluded that spatial ability is related to the learning of scientific topics. The research report was confined to volcanic eruptions, a topic about which the students did not have more than a minimum amount of prior knowledge. All the students in the experiment read a text association with volcanic eruptions. One group of students was given illustrations and animated images of a volcanic eruption. The second group of students did not have the visuals. The researchers observed that when the two groups of students in the study were compared in their success at constructing mental animations from non-illustrated text or text with static illustrations. The benefits of the animations were evident in the analysis (Sanchez & Wiley, 2007). This research based on spatial thinking among university students is similar to the current research in which university
education students are engaged. The study by Sanchez and Wiley (2007) demonstrated that animations with their spatial attributes of movement, connections, and location are important in helping students learn more spatially. It also reinforces that the belief that spatial thinking should be a component of the undergraduate pre-service teacher education experience where spatial concepts may be imbedded within earth science and geography instruction.

A common application of spatial thinking is the estimation of distance. The research by Bridgeman and Hoover (2008) suggested that distance estimates are often overestimated. In field-based interviews, participants were asked about distance estimates and their spatial familiarity of their surroundings. The results of the research suggested that distance is not accurately estimated. The way the individual perception of distance is a major influence on the actual distance reported. The complexity of spatial thinking relative to real world experiences, such as estimating distance, was suggested by the research.

Research has also been completed regarding the steepness of a slope and the apparent slope difficulty by individuals expressed through verbal communication or physical mobility. Bridgeman and Hoover (2008) suggested two reasons researchers may expect differences in slope estimations: stronger effort required to walk up an incline and different neural processing of landmarks and surrounding space. The researchers compared a motor measure that determined physical exertion with a verbal measure to estimate slope. The exertion, or motor, measure was more accurate than was the verbal descriptive measure for estimating slope. The research further revealed that large errors
in estimation were made by individuals when assessing a spatial layout of their surroundings (Bridgeman & Hoover, 2008).

**Neurological Spatial Processing**

Spatial cognition is linked with the neurological functions of the brain (Burgess, 2008) and research is showing that particular locations in the brain process particular types of spatial thinking. One of those spatial thinking elements is location. Research suggests that the egocentric representations of locations in which the student views their particular location as the dominant factor is stored in the brain and updated by our own movements and intentions to move (Burgess, 2008). The brain is continuously processing concepts of space and our surroundings as people adjust to new spatial contexts.

Lobben (2008) suggested that newly emerging visualization experimental methodologies in visualization can enhance the scientific design of experiments. For example, focus groups may serve as an excellent resource for qualitative data. Animated methods can be used as variables in science teaching and learning. Lobben (2008) reported that cartographers are most aware of image properties and the effects they might have on the visualization of geographic information. Cartographers are skilled at developing various methods of representing different data properties associated with mapping methods such as the shapes of points, lines, and polygons on maps.

**Spatial Thinking and Virtual Geography Applications**

One of the challenges of geographic education is to prepare students with the strategies for spatial thinking (National Research Council, 2006). The use of virtual
globes and digital maps may enhance students’ abilities to learn and apply spatial concepts. Google Earth is an example where mapping and geographic information are merged for students to both manipulate and visualize information. Some researchers believe that when students can view their own home or a location near their residence, they can develop the strategies of making comparisons and connections that involves spatial thinking. Other web based access to global data with capabilities similar to Google Earth offer a unique advantage in the implementation of spatial thinking. For example, Joseph Kerski suggests that engagement with geo-technologies moves the students into the realm of spatial thinking (Kerski, 2008).

Researchers and educators are continuing in their pursuit to identify more specifically the concepts and processes in spatial thinking (Kerski, 2008). Access to digital mapping tools and internet-GIS are increasing for both school and non-school tasks that use spatial thinking as a practical cognitive skill (Kerski, 2008; Gersmehl, 2008).

The use of digital globes is considered a virtual tool in the spatial learning by students through inquiry as a main pedagogical approach (Schultz, Kerski, & Patterson, 2008). Spatial thinking incorporates processes that include an interconnection of spatial questions including those of spatial ability, spatial concepts, spatial reasoning, spatial cognition, spatial intelligence, environmental cognition, mental and cognitive mapping, and mental maps (Black, 2005; Gardner, 1983; Golledge, Marsh, & Battersby, 2008; Gould & White, 1986; Linn & Peterson, 1985; & National Research Council, 2006).
Spatial Primitives and Concepts

Golledge, Marsh, and Battersby (2008) suggested that all learners benefit from effectively taught and presented geospatial concepts that engage students in spatial thinking. Four levels of spatial thinking particularly relevant to the current research were proposed by Golledge, Marsh, and Battersby (2008) and referred to as spatial primitives. Location and the recall of location are a major theme that is evident in all stages of the human life and serves as an important primitive. Other lower-order primitives include: identify, magnitude, and space-time. University students are expected to use higher level spatial concepts such as those proposed by Gersmehl (Gersmehl, 2008). Golledge et al. (2008) and Gersmehl (2008) both propose that geospatial thinking is embedded in everyday life and people use it unknowingly. Both researchers expressed it is too often taken for granted and rarely receives enough curricular or instructional attention in classrooms.

Golledge, Marsh, and Battersby (2008) researched the benefits from using maps with lower order or simpler concepts. The geospatial concepts they researched were presented in an ordered sequence through a series of paper-and-pencil or field tasks. The tasks served, according to the researchers, as the foundation for learning spatial concepts as taught in the classroom (Golledge et al., 2008). Golledge was in search of a framework that would order the scope and sequence of the geospatial concepts, based on the belief that current practices were in need of an upgrade (Golledge et al., 2008).

Training students to think spatially is important in a science curriculum. The need for students to learn spatial and visualization skills of interpretation is associated with technology, and the use of technology in classroom instruction. The research on this topic
to date further emphasizes the need for a curriculum that systematically presents spatial thinking as a cognitive skill with wide ranging applications. Much of the research has been with the visual representation of maps and other graphic materials, which is the immediate interest of those researchers with a background in geography. Spatial representation may be used to develop models in order to summarize or apply abstract information to the explanation of complex causal phenomena. The spatial relationships among the parts within a spatial graphic or diagram presents a challenge for novice learners (NRC, 2006). The NRC summary of research (2006) suggested the power of spatial thinking is within the problem solving and decision making attributes it complements. The summary further suggested that students enter the science classroom with a spatial toolbox which can be applied to those tasks that make up the school curriculum.

**Wayfinding**

Gauvain (1993) suggested that spatial thinking is useful in everyday activities, such as directional movement when walking and driving to a destination. Gauvain (1993) argued that it is critical to understand the cultural context in which an individual is using a directional framework. Her research also suggested that other factors may influence spatial cognition.

In addition to studying the amount of exposure to space and its relation to spatial thinking and problem solving, researchers have also investigated how type of exposure, including physical active versus passive movement, self- versus other-directed exploration, and the number of vantage points accessed, may relate to spatial cognition (Gauvain, 1993, p. 107).
The evidence suggests that spatial thinking and skills associated with it are highly relevant to movement, everyday travel, and even recreation hiking. Research also suggests that the processes which facilitate spatial thinking are influenced by the context and nature of the activity. Cultural experiences and environmental situations are also believed to be an important aspect as well (Gauvain, 1993).

Klippel, Tappe, Kulik, and Lee (2005) in more recent research suggested the importance of a theory they called: *wayfinding choremes*. The concept of wayfinding choremes was proposed originally by a French geography, Brunet (1980). The individual’s source of a language for communicating and functioning across earth space was the fundamental principle Brunet (1980) was interested in explaining. Route knowledge is a major component of the theory and is based on mental conceptualizations of directions at particular decision points. Brunet’s wayfinding choremes represent concepts such as mentally turning and non-turning, which may be similar to mental rotation such as those necessitated at a street intersection. In route planning, those locations are identified as decision points that are relative to point locations along a route (Klippel et al., 2005). The route that an individual may select from the origin of a journey to the destination can be mentally conceptualized. The mental route, according to the theory of wayfinding choremes, consists of chunking together the different elements of the skills of mobility and mental cognition in order to analyze and make decisions regarding actual route selection, route direction, and other sets of wayfinding actions (Klippel et al., 2005).

Several researchers association wayfinding with the work of taxi drivers and they investigated the drivers’ spatial thinking relative to the tasks they perform (Spiers &
Maguire, 2008). Wayfinding by taxi drivers was presented as an aspect of spatial thinking related to everyday travel and route planning. The ability to think spatially in the context of wayfinding was assessed through sketch mapping and descriptive verbal explanations of the movement between several locations. Results suggested that the taxi drivers in several European cities, including London and Paris, exhibited a range of spatial thinking processes. In the initial planning research there were three spatial processes identified. They were: 1) retrieving the location of the destination, 2) determining the direction to the destination, and 3) retrieval/selection of the streets to form the route (Spiers & Maguire, 2008). A specific category which emerged from this study was the visual connection with physical features along the route during wayfinding. Landmarks and other physical features were important to visualize orientation during movement. Reaching the destination provided clues about spatial thinking when research subjects, such as the taxi drivers, are asked to verbalize or ‘think out loud’ during the process of wayfinding.

The ability to use and create spatial representations is an essential part of spatial thinking (Jo & Bednarz, 2009). The researchers examined geography textbooks to determine whether questions in the textbooks addressed spatial thinking skills. They proposed that questions in textbooks should focus on the implementation of spatial thinking processes and ask students to apply essential spatial concepts and implement high-level processes related to spatial thinking (Jo & Bednarz, 2009). Evidence from the research suggested that key spatial concepts such as pattern, diffusion, and hierarchy are rarely included in textbook questions. They recommended that textbooks incorporate
questions which enhance spatial thinking skills, including the concepts of space, tools of representation, and reasoning processes.

Transformation reasoning is a powerful concept (Ramadas, 2009) and entails complex mental representations useful in the learning of science using visualization skills. The transformation entails the conversion from conceptual elements into diagrams that represent descriptions with direct applications. Verbal dialogue and motor skills are embedded processes frequently associated with spatial transformations (Ramadas, 2009), such as providing a detailed verbal narrative or discussion centered on a spatial task.

Sanchez and Branaghan (2009) investigated the advantages and disadvantages of providing increased displays of pictorial features on a map where the participants were asked to recall a marked route. Results of the study using undergraduate student participants suggest that students remembered more and learned more efficiently with maps that had low-resolution displays as opposed to high-resolution pictorials. The maps used in the experiment showed urban places. The study suggested that more generalized map displays showing less detail allowed students to recall map information more efficiently (Sanchez & Branaghan, 2009). The research suggested that maps with high resolution graphics and excessive pictorial content are more difficult for undergraduate students to use. There was moderate association for students with greater spatial visualization skills and their ability to remember a route in high-resolution displays, but no levels of statistical significance were reported (Sanchez & Branaghan, 2009).
Spatial Thinking and Geographical Information Systems (GIS)

Lee and Bednarz (2009) examined the effect of GIS learning on the spatial thinking ability of university undergraduates. GIS is widely used with students in geography and purported to be an important application of spatial thinking. The researchers evaluated performance on a pre- and post-test of spatial thinking before and after an experimental treatment entailing the study and application of work with GIS. The pre- and post-tests were completed by the undergraduate students and were comprised of equivalent questions measuring the same spatial thinking abilities (Lee & Bednarz, 2009). The results from the research found that greater improvement occurred with the students who had the most experience within the GIS treatment. Lee and Bednarz (2009) evaluated three sets of spatial abilities related to student performance on pre- and post-tests: spatial visualization, spatial orientation, and spatial relations. Lee and Bednarz (2009) noted

As expected, post-test scores have a stronger correlation with the lab exercises than class exams. Because the lab exercises were relatively simple (i.e. demanding few cognitive processes), it is possible that the size of the correlation coefficient (0.405) underestimates the actual relationship between spatial thinking and hands-on application of GIS to solve problems. The simplicity of some of the problems faced by students in the labs was mentioned by several study participants (p. 195).

The improvements in spatial thinking skills were attributable to the students’ GIS experimental treatment and experiences (Lee & Bednarz, 2009). According to the conclusions reached by the researchers, a GIS course or experiences with exercises in map analysis are important in helping students develop their ability to think spatially.
Virtual and Non-Virtual Experiences in Spatial Thinking

Research has also shown that the transfer from virtual to real-world environments in route learning requires the use of spatial thinking (Lloyd, Persaud, & Powell, 2009). The strategies in route-learning are use of landmarks as important features with the development of a mental map often being an anchoring concept for the individual. Those components, especially the mental map, combine to form a reference system that is used to sequence memorization, and anchors the recognition of landmarks in both exact and relative locations (Lloyd, Persaud, & Powell, 2009). The researchers applied a virtual-reality route learning to determine the effects of multiple turns in a route memorization task in Birmingham, United Kingdom. The pilot test evaluated participants and their time of completion of the routes. The researchers reported that the route-learning ability can be assessed through these processes of learning from a virtual town and applying it to the real-world situation (Lloyd, Persaud, & Powell, 2009).

Summary of Theoretical Foundations for the Present Research

The research and theoretical writing from the literature that has had a major impact on spatial thinking in recent years is that by Gersmehl (2006; 2007; 2008). The development of the modes of spatial thinking was attributed to an extensive review of over one thousand literature articles. A recently updated review of literature narrowed the modes of spatial thinking from thirteen to eight. The purpose of Gersmehl’s literature review was to create a narrowed list that exemplified the numerous studies on the
cognitive skill of spatial thinking and how people use this skill to perform various spatial tasks.

Gersmehl's research in spatial thinking progressed into the more defined set of eight modes. These modes represent the foundation for this dissertation research study. A review of extensive literature in psychology, geography, and other related geosciences served as the basis in which the core modes of spatial thinking were determined. Three spatio-temporal modes are also identified. Six of the eight core modes of spatial thinking were determined to be embedded in the Geography 1900 course at Western Michigan University. Many inquiry-based activities within the course applied the modes of spatial thinking through the interactions and student conversations in completing course tasks. It was the intent of this research to focus on the development within the population of students enrolled.
CHAPTER III

RESEARCH METHODOLOGY

Mixed Methods Research Design

This dissertation research consists of data acquired through a mixed methods research design. A pre-post test was used in the collection of quantitative data, as well as measures of performance on map and diagram drawing tasks that are readily quantifiable. The qualitative data were based on interviews, observations by the researcher and assistants, and empirical observations that were analyzed from recorded discussions and open ended narratives, both written and spoken. The null hypothesis suggests that pre-post test means are equal. In my judgment, the research design permitted data collection that enabled me to answer the six research questions stated above. The three hypotheses developed for the research are based on the questions and the effects of the completion of spatial thinking assessment tasks on pre-service elementary teacher education students’ ability to apply spatial thinking.

Qualitative Methodology

This research study is a phenomenological qualitative methodology. Phenomenological studies are important for research studies which concentrate on a phenomenon (Creswell, 1998). Spatial thinking is an important cognition skill and
phenomenon. Participant observation is also involved in this qualitative portion of this study.

The phenomenological method began as a philosophy which is related to the essence of a phenomenon or object as it presents itself in human conscious. The essence of what humans experience with the phenomenon is of great importance. In spatial thinking, people will exhibit different experiences of cognitive thought. As spatial thinking is a collection of cognitive skills, the study of these skills for humans will serve as the phenomenological study. Because the researcher wants to investigate the ways in which undergraduate pre-service teacher education students use different modes of spatial thinking, the phenomenological method is an effective qualitative study. By looking at the ways in which students express their spatial thinking, the researcher studied the physical movements and verbal reasoning relative to their cognitive thoughts.

Sanders (1982) proposed that there are three fundamental components in a phenomenological research design. They are: 1) the aspect of determining the limits or what and who is to be investigated; 2) collection of data; 3) and the phenomenological analysis of the data. The present study has certain limits. They are: 1) the study involves college-age students who are above 18 years of age; the number of students who volunteered for the spatial walk in the first semester of research was sixteen; 3) the students were from one course with two sections Fall 2008 and three sections Spring 2009 in Geography 1900; 4) the number of students participating in the second semester spatial walks was seventeen; 5) eight students from Geography 1020, the comparison group, participated in the spatial walk during Spring Semester 2009. The selection of the Geography 1020 students was randomized from the enrollment roster.
The phenomenon which is being studied is spatial thinking. Examples of the qualitative techniques the researcher used were observations in the classroom and walkthrough tasks on the campus of Western Michigan University. The subjects were engaged in actual spatial tasks so that their thinking and physical movements were observed. There were interviews to examine the particular behaviors in-depth. The interviews were transcribed from the video recordings and interpreted. The student names were coded to ensure confidentiality.

As indicated in the Sander’s (1982) paper, analyzing the data requires four levels of analysis. The four levels are: 1) a description of the phenomenon through interview transcripts; 2) identification of emerging themes; 3) the subjective reflections on the themes; 4) and the abstraction of the essences. The description and essences were selected as the main levels for this research because this is a step-by-step process of integrating multiple sets of data. The description level is indicative of the concurrent interviews from the spatial walk.

The identification of gender differences was not an objective in this research study, due to high percentage of female students in the sample. This study focuses on identifying differences between and within groups on pre and post-tests resulting from a particular set of spatial treatments. The qualitative data are mainly concentrated on the identification of the modes of spatial thinking students demonstrated in activities and spatial walks (Gersmehl, 2008).

A phenomenological study can follow a psychological approach in which the study is often an interpersonal topic relating the phenomenon to human subjects (Creswell, 1998). This phenomenological differs from the physiological study since it
examines the students’ ability to think spatially as a cognitive process. This is the essence of the research.

**Spatial Walks on the Campus of Western Michigan University**

The students in this study participated in a pre-post written test assessing their spatial thinking. A sub-sample of those students also participated in a spatial walk where they reflected on their modes of spatial thinking in an interview during the walk. Each individual spatial walk resulted in a transcript of the student’s comments. They were word processed verbatim by the researcher. The data collected during the spatial walks was treated in the same manner as described earlier for the classroom observations of Geography 1900 and consistent with an open coding scheme and emerging categories as grounded theory (Strauss & Corbin, 1990, pp. 23, 61) with two distinct caveats.

First, the spatial walk data was completed by just the researcher. The interview protocol was used to retain stability and consistency in the interview items. Each spatial walk was audio recorded for the preparation of transcripts.

Second, the researcher was the only person to review and analyze the transcripts from the spatial walks. The researcher applied the same rigor to the observational process as was applied with the classroom observations where there were two additional observers. In part, this is the difference between well funded research where others can be engaged and paid for assistance and research where the principal investigator is the only person collecting and interpreting the data. In such instances the final judgment on the accuracy and depth of analysis is left for replication studies in the future.
Seven interview items were asked during the spatial walk from Wood Hall to Goldsworth Valley in which students responses were recorded (Appendices A, B). An open coding scheme was developed that was used to code terminology used by the students that reflected the modes of spatial thinking and other emerging concepts. The open coding scheme required a “breaking down, examining, comparing, conceptualizing, and categorizing data” that were collected in response to the spatial walk questions (Strauss & Corbin, 1990, p. 61). The identification and selection of categories is a process in open coding. The categories were derived by the researcher from pertinent vocabulary words in student responses to interview items. The pertinent vocabulary words relative to modes of spatial thinking or other spatial concepts were not listed beforehand in order to reduce researcher bias; common vocabulary words and patterns with other associated words were identified by the researcher by a thorough examination of the transcript data. This scheme was used in the deconstruction of the spatial walk transcript data. The table constructed by the pertinent vocabulary and emerging categories is presented in Chapter IV.

Glaser and Strauss (1967) developed grounded theory as a qualitative method. Theory emerges from a study of the phenomenon. Spatial thinking is the phenomenon of study in the present research. In accordance with grounded theory, themes and patterns that emerged from the analysis of the transcripts were then prepared as categories for analysis from the open coding scheme (Strauss & Corbin, 1990). The analysis is derived from the concurrent interview data collected during the spatial walk. The analysis of the transcripts suggested that modes of spatial thinking and other spatial concepts were
reflected by the students, but not as specific vocabulary terms. The spatial modes that emerged as the result of the conversations will be discussed in Chapter IV.

A total of twenty seven students from Geography 1900 participated in the spatial walk segment of the research for Fall 2008 Semester and Spring 2009 Semester. The walk was a transect across a familiar part of campus from Wood Hall to the Goldsworth Valley. Eight students from Geography 1020 participated in the spatial walk during Spring Semester 2009. A camcorder was used to record the path of the walk and the interview questions and responses, but did not reveal facial features of the participants. The full list of interview questions from Wood Hall to Goldsworth Valley is presented in Appendix A.

Students in Geography 1900 were requested to volunteer to complete the spatial walk and observation procedure. Students in Geography 1900 volunteered on an invitation sheet that was distributed in class for Fall Semester 2008 and Spring Semester 2009 (Appendix I). When there were more volunteers than necessary, the researcher randomly selected twenty students from the sample of volunteers. If there were fewer students than twenty who volunteered, then all the students from the volunteer list were included in the spatial walk. The eight students from Geography 1020 were randomly selected and invited to participate in the spatial walk and observation. The effects of motivation, reward, or interest in the project by students who volunteered were not considered in the data collection or analysis.

Student identification for the spatial walk was coded for anonymity. Neither the audio nor video portions of the spatial walks did include student identification. Full
transcripts were analyzed and assessed for indicators of spatial thinking. A sample transcript is presented in Appendix B.

As in all qualitative research, greater information and dialogue may result from certain questions and individual students respond in particular ways. This was noted by the researcher after the end of the recorded spatial walks. The purpose of the questioning of the students along the walk was to infer cognitive processes the students used and their ability to think spatially. Interview data of the spatial thinking modes reflected in their verbal descriptions along the walk were analyzed. The walk permitted the researcher to determine the spatial thinking skills that students transferred from the course syllabus and the inquiry-based learning from the classroom to the out of doors context.

The outdoor setting was the central campus of Western Michigan University. The walk required students to begin at Wood Hall (near their Geography 1900 classroom) and walk to the Goldsworth Valley as instructed by the researcher. During the walk, interview questions were presented to students at intermittent points. The intermittent points were held constant and thus were the same for each individual who participated. There were no dangerous intersections or traffic conditions that presented safety issues for the walking students.

Observations in the Geography 1900 Course

Seven inquiry-based activities were observed by the researcher and trained observers, and recorded through videotaping and observational notes. The Geography 1900 activities observed included: Topographic Maps, Mapping I, Mapping II, Sun Angle, Length of Daylight, Winds II, and the Lake Effect. Based on the evaluation of the
Geography 1900 syllabus, these activities represent the greatest reflection of the modes of spatial thinking (Gersmehl, 2008).

A systematic recording schedule was established in order to sample the functioning of the course and students every fifteen minutes. For purposes of inter-rater reliability, two graduate students were hired to observe a limited number of activities. This was necessary to obtain an estimate of stability by the researcher for the observational recording process in the data collection and interpretation. The purpose of a second observation of the same scenario is to provide inter-rater reliability for the measurement or rating. A high inter-rater reliability suggests the data collection and interpretation were stable and consistent, and enhances the quality of the research and its findings. A low reliability level makes the data and process suspect and less stable for interpretation.

The behaviors by the students relative to the six core modes and three spatio-temporal modes of spatial thinking were rated on a zero to seven point scale. Prior to the observations, the graduate students retained as raters met with the researcher to review Gersmehl’s modes of spatial thinking. Each mode of spatial thinking that would be verified in the activities was reviewed and defined on the basis of Gersmehl’s taxonomy. The individual observations of the classroom were independent, with the graduate student raters receiving the list of spatial modes of thinking in advance. Those observations made by the trained observers are included in Chapter IV. It was not necessary to complete an inter-rater reliability for every observation. Rather, a sampling was made on the premise that if the sample were reliable, then the ratings by the researcher would be stable and
reliable. Two activities were observed solely by the researcher while the co-observers with the researcher observed five.

The students from Geography 1900 were observed by trained observers, while the KVCC earth science class and the Geography 1020 classes were not.

**Instructional Methodology**

The research did not specifically compare methods of instruction. It should be noted that Geography 1900 students proceeded through the seven instructional activities following an inquiry model, while the Geography 1020 students were presented a self-study, guided instruction model for the completion of the map and atlas exercises.

The inquiry based-approach is a widely accepted methodology in the teaching and learning of science. The National Science Education Standards (National Research Council, 1996) defines inquiry as a teaching pedagogy and learning goal. Students are actively engaged in the learning process and observation and experimentation are generally major components. Students follow the same processes as scientists do in the inquiry methodology. Geography 1900 is a laboratory-based class with laboratory experimentation and observational tasks designed for student engagement where students discover science concepts and content through inquiry. Rutherford (2001) suggested that science is a way of looking at the world, instead of a list of facts and principles to learn by rote memorization.

The inquiry approach is much different than the traditional lecture. In inquiry pedagogy, students are actively engaged in the learning process and discover the big concepts of earth science. Inquiry is important as a methodology used by scientists in the
actual processes of science. Ruhf (2006) identified the dominance of inquiry in science education as a result of curriculum reform in the 1960s. The curriculum reform during this time focused on the concepts of teaching science instead of memorization and isolated facts (Ruhf, 2006). Curriculum studies emerged which transformed science in the classroom into an inquiry-based pedagogical approach. These studies include the Physical Science Study Committee (PSSC), Biological Sciences Curriculum Study (BSCS), the Earth Science Curriculum Project (ESCP), and the High School Geography Project (HSGP). These projects were funded by the National Science Foundation (NSF) (DeBoer, 1991).

Inter-rater Reliability

Reliability has practical significance for qualitative research. In order for the researcher to be certain that the same standards and criteria were being applied to the interpretation of non quantitative data collected and analyzed. The reliability was addressed by retaining and training two advanced graduate students to complete a second and third review of the recorded classroom observations. They observed the interaction of the students and conversations about the content during the class sessions. The researcher and the other raters made their ratings of the modes of spatial thinking used by students in their classroom discussions. There were three classes co-observed within the classroom during the research period in Spring Semester 2009 and two classes were observed using the video recordings. The observation and rating of the video recorded classes were included in the determination of inter-rater reliability.
The inter-rater reliability for the classroom observations was completed using the observers' ratings and the Pearson Product Moment correlation. The correlation among the three raters observing the classroom instruction was .78 exhibiting a positive degree of stability in following the observational protocol. Thus, the researcher concludes that a high degree of stability and reliability in the rating process and the ratings of attention to spatial thinking were attained. During the meeting which followed the observations, a mean ranking based on all three observers was determined.

**Geography 1900 Observations**

The classroom observers who assisted in the establishment of inter-rater reliability were colleagues in the Mallinson Institute for Science Education. They were trained by the researcher prior to the actual observations using a specific protocol method (Appendix E). The protocol was a modified lesson observational system of Science and Mathematics Program Improvement at Western Michigan University (SAMPI, 2003). Questions posed by the raters were guided by the protocol and were addressed in meetings with the researcher prior to and following the class observations. The observations and ratings occurred throughout the semester on a predetermined schedule that permitted the most complete coverage considering cost and resources.

Following each activity in which reliability data were collected, the raters met with the researcher and compared the observations for the spatial modes embedded within the activities. The ranking systems and rationale were discussed during the meeting. A review of the notes and observations during the class session permitted differences and similarities to be identified. For each observation (Appendix E), the raters
classified the modes of spatial thinking exhibited based on relevant exchanges (7 = High) in dialogue within the context of the context for that class session as well as duration of time. In addition to the direct observations in the classroom there were audio/video recording taken of the seven instructional activities in Geography 1900.

The same individuals who were trained as observers/raters also observed a sample of the video tapes recorded during each class session and applied the observational protocol. Prior to beginning the video review, the modes of spatial thinking were reviewed for the observers (Gersmehl, 2008). The modes of spatial thinking that were assessed during video analysis were reviewed for the raters. During the video analysis there were no conversations among the raters and the researcher. A discussion followed the rating of the video tape was held to clarify any questions and to resolve any major classification of the mode of spatial thinking assigned to particular segments.

Quantitative Methodology

The Spatial Thinking Test

The Spatial Thinking Tests was constructed and validated within a prior research study (Lee, 2005). The test was designed as a paper-and-pencil test that was developed for Ph.D. dissertation research. Lee (2005) constructed the items based on the following: 1) identification of the test purpose and specification of concepts measured; (2) construction of the initial pool of items; 3) pilot testing; 4) item analysis; and 5) field testing (Lee, 2005, p. 46). The delineation of the assessment objective was the first process in Lee’s (2005) construction of the spatial test items. Selected items were further
administered to undergraduate students in a pilot study at Ferris State University along with the full pre and post-test that was used in the research.

The researcher added two items to Lee’s (2005) test that were designed for content specificity related to Geography 1900. The earth-sun relationship and precipitation items were examples of the content validity in the Spatial Thinking Test. The construct validity, such as the mental rotation tasks and shape arrangements that were not specifically related to the course content, were used as spatial thinking construct items. The inclusion of spatial thinking construct items from prior tests provided assurance that the modes of spatial thinking were not an achievement of the content in Geography 1900 by students, but these items were actually measuring constructs related to spatial thinking and used in prior research in psychology, geography, and earth science. The researcher’s alignment of the modes of spatial thinking with the test items is presented in Appendix M.

Students were administered a pre and post-tests in Geography 1900 and Geography 1020 for Fall 2008 and Spring 2009 semesters; students in an earth science course at Kalamazoo Valley Community College (KVCC) were also administered the tests in Fall 2008 semester. The spatial tasks included a paper map analysis, navigation, and contour drawings. The test packet included eighteen individual spatial tasks. The pre-tests and post-tests were identical in content for their similar spatial tasks, although the arrangement of the items was different between pre and post-tests. The pre-post tests repeated measures was the methodology used research for the quantitative segment of the mixed methods design (Campbell & Stanley, 1963). The design of the research was quasi-experimental, since it did not employ random assignment of subjects. Specifically,
the study is a non-equivalent group quasi-experimental design. No random pre-selection process occurred within this study. The experimental group, students from Geography 1900 and KVCC, represented the independent variable. The comparison group, students in Geography 1020, represented the comparison group that received an entirely different course treatment. Overall, the student participants were not randomly selected from these courses. There were randomly selected students drawn for sub-sample assessment randomization procedures in the Geography 1020 spatial walk, such as random numbers. Those students randomly selected were from Geography 1020, a larger enrollment class, and invited to participate in the spatial walk.

Analysis of Variance (ANOVA) test was used to assess for differences between the sub-samples from the two courses. ANOVA statistics were used to determine if there was a significant relationship between or within the three groups (Geography 1900, Geography 1020, KVCC).

Sample Selection

Western Michigan University

Western Michigan University is located in Kalamazoo, Michigan, with an approximate 25,000 student enrollment. Approximately 90% of the students enrolled in Geography 1900, Earth Science for Elementary Education students were female. Students from first year freshman to final semester seniors were asked to participate in this study. Most students enrolled are between the ages of 18-23 in undergraduate courses at Western Michigan University. However, a limited number are non-traditional older
students. In order to produce results that can be generalized, the entire population or a randomly sampled selection should be used in research (Ray, 1985). This was not possible due to the enrollment procedures for the course. Therefore, the current study will be grounded in the collected data and generalized to this particular group of students. The study sample is representative of the population of students who enrolled in Geography 1900 during Fall Semester 2008 and Spring Semester 2009. All students in Geography 1900, Geography 1020, and KVCC class were provided consent to participate in the pre-post tests.

Geography 1900: Experimental Group

This study occurred at Western Michigan University in Kalamazoo, Michigan from 2008-2009. Five individual Geography 1900 sections taught at Western Michigan University during Fall Semester 2008 and Spring Semester 2009 represented the focus of the experimental design in the research study. Geography 1900 used an inquiry-based syllabus. Four Geography 1020 sections from Fall Semester 2008 and Spring Semester 2009 represented the comparison class which did not use the inquiry-based syllabus.

Geography 1900 is a laboratory-based course designed for pre-service elementary teacher education students. In the inquiry approach, students are engaged in numerous activities which allow them to discover the principles and concepts of earth science. Students work in groups of four at individual laboratory tables and discuss the procedures, problems, and outcome questions related to the inquiry activities. All Geography 1900 students in this study were taught by one instructor, and not by the researcher. The experimental sample of students from the combined Fall 2008 and Spring
2009 semesters totaled one hundred twenty students. A total of twenty seven Geography 1900 students from combined Fall Semester 2008 and Spring Semester 2009 volunteered to participate in the spatial walk by placing their name on a volunteer list.

During the first and second weeks of each semester, the researcher introduced himself at the beginning of the course, and the researcher explained the nature of the study while asking for students to participate. Consent forms authorized by the Human Subjects Review Board (HSIRB) of Western Michigan University were distributed, signed by the students, and collected (Appendix C). The data collection was valid one year from the originally date of authorization: April 13, 2008. Students were given official National Geographic maps of either the United States or Africa as a reward for their participation in the research project. Students who participated in the spatial walk were given an official Mallinson Institute for Science Education mug at the conclusion of their participation as a reward.

**Geography 1020: Comparison Group**

The use of a comparison group is an important aspect in research design, especially one with clearly defined statistical methods (Liao, 2002). Geography 1020 was selected as the comparison group in the study and is identified as a non-equivalent group. The comparison group used a textbook and world atlas.

Atlas use was a fundamental component of the course content and exercises and was expected to have some impact on spatial thinking since individual study tasks applying scale, map symbolization, information extraction and reformulating as narrative descriptive statements were completed by the comparison group students. The
comparison group was necessary to compare the effects of content materials – laboratory learning experiences based on the seven activities in Geography 1900 with self-study using maps and atlas exercises. The Spatial Thinking Test is a measure of spatial thinking constructs rather than spatial thinking achievement. It was not designed specifically for either the experimental or the comparison course with the exception of the two content items that were added to measure specificity of learning of Earth Sun relationships and the effects of elevation of atmospheric conditions. The two items added were not included in the initial Test of Spatial Thinking used by Lee (2005), but were deemed important since both content areas included specific content about spatial relationships at the scale of the solar system and Earth system that affect atmospheric conditions.

Students enrolled in Geography 1020, World Geography Through Maps and Media, served as the comparison group. Seventy nine student and ninety one students, during the Fall 2008 and Spring 2009 Semesters respectively, represented the comparison group. The inquiry-based laboratory manual, which represents the experimental source for this study, was not used in the Geography 1020 course.

Geography 1020 is represented by the following characteristics: 1) a lecture-based course; 2) a major component of map and atlas use projects signed to a) build map and spatial skills and b) interact with geographic content on maps; and 3) As with Geography 1900, there was no direct attempt to teach Gershman’s (2008) modes of spatial thinking, but they were embedded in the individualized atlas projects.
Kalamazoo Valley Community College

One earth science section using the same syllabus was taught to Kalamazoo Valley Community College (KVCC) students. These students were included within the experimental group for Fall Semester 2008, although in the statistical analysis the group is separate. The Instructor at KVCC used the same syllabus and classroom activities. The KVCC Instructor noted that KVCC did not have all of the necessary materials required in the laboratory for all activities in the course packet.

Demographics of the Population

The experimental groups, Geography 1900 and KVCC, consisted of a much higher percentage of females. In comparison, a larger number of males enrolled in Geography 1020 although the number of females exceeded males. Tables 2 and 3 represent demographics for the three groups (Geography 1900, Geography 1020, and KVCC) in Fall 2008 and Spring 2009 semesters.

Table 2: Demographics for Fall Semester 2008 Sample

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geography 1900</td>
<td>4</td>
<td>39</td>
</tr>
<tr>
<td>Geography 1020</td>
<td>30</td>
<td>49</td>
</tr>
<tr>
<td>KVCC</td>
<td>3</td>
<td>13</td>
</tr>
</tbody>
</table>
Table 3: Demographics for Spring Semester 2009 Sample

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geography 1900</td>
<td>8</td>
<td>53</td>
</tr>
<tr>
<td>Geography 1020</td>
<td>28</td>
<td>63</td>
</tr>
</tbody>
</table>
CHAPTER IV

RESULTS

Analysis and Reporting of the Qualitative and Quantitative Data

Spatial Walks: Research Questions and Reflections

One objective of the research was to determine if the modes of spatial thinking defined by Gersmehl (2008) were reflected in the conversations by students outside the classroom, and if this was linked to their classroom instruction in Geography 1900. The percentage of students using the various modes of spatial thinking was calculated after analyzing the transcripts. These qualitative results were garnered using principles of qualitative research presented by Sanders (1982). The analysis entailed the deconstruction of recorded conversations, identifying indications of spatial thinking, associating them with Gersmehl’s (2008) modes of spatial thinking, reconstructing the contextual meaning and making an inference to the effects of the Geography 1900 course on student behaviors. Geography 1020 student transcripts were assessed, although parallels in responses limited the differences between these groups. The behavior and responses of the Geography 1900 students represented the concentration in the spatial walk analysis. In presenting the responses for the spatial walk in this research, three excerpts were selected from the interviews to demonstrate three levels of responses: 1) an elaborate response; 2) an acceptable response; and 3) brief response pattern.
Analysis of Spatial Walk Transcripts and Reflections

The interview items selected for the more detailed discussion are presented according to each interview item. A more detailed presentation of the full transcripts is presented in Appendix B.

Interview Item 1: "We are beginning a walk through part of campus. Our destination is Goldsworth Valley. You may be familiar with the route. Using the knowledge of where we are presently, and the location of Goldsworth Valley, which we cannot see from here, describe any information that you need to consider in order to be certain that we will arrive at our destination by the end of the walk.

The following map indicates the starting point, Wood Hall, surrounding buildings, and the end point Goldsworth Valley at Western Michigan University (Figure 1).

![Map of Western Michigan University Campus](image)

Figure 1. Map of Western Michigan University Campus.
The following responses were received from the experimental group, Geography 1900 students, who participated in the walk. The students responding were outside of Wood Hall on the eastern side of the building. In response, the Geography 1900 students expressed that a plan or a reference point was needed to reach Goldsworth Valley or the Bernhard Center. One student commented:

1.) A lot of people, this being my first year on campus, will point me to different places by saying you need to go up to this building in front of us and take a left, and then you’re going to go up to that building and turn right. That’s pretty much all I needed, so far this semester.

The campus buildings represented a fixed reference point for twelve (36%) of the Geography 1900 students. In many of the other cases, a map or a compass represent an essential aspect of finding a destination. Twenty one (64%) referred to maps as being an important part of reaching any particular destination. One student confirmed this in the answer:

2.) A map, possibly. A good reference guide like maybe someone who has been here for a while. You could ask them. Basically, a map. Last year, I had a map to figure out where I was going. And buildings.

Students also commented that a directions and compass directions are important in reaching a destination.

3.) Um, maybe to know spatial directions: north, south, northeast, southeast, northwest.

The analysis of a map is a process of identifying location and interpretations of the conditions and connections of features. Connections are made by two locations on the map, which in this case would be Wood Hall and Goldsworth Valley or the Bernhard Center. The core spatial thinking mode is comparison as students can interpret conditions
and make connections between two locations. According to Gersmehl (2008),
comparison entails the identification of how places are similar or different. These
students demonstrated that by: 1) making verbal comparisons and connections between
physical features such as buildings; 2) understanding the physical features on a map; and
3) comparing the location of buildings and other features with direction.

Interview Item 2: “Identify any objects in which you see that will be helpful in order to
reach your destination.”

The buildings and other physical features represented a category of objects that
students identified while reaching their destination. Objects such as flagpoles, buildings,
the WMU sign, and other landmarks were identified by students of Geography 1900.
Twenty (74%) of Geography 1900 students identified the flagpoles as being the most
prominent landmark on campus. Geography 1900 students commented:

1) Well, I would say for one thing the flagpoles in the center of campus is definitely
a pretty distinguishable landmark. Of course, you have Sangren Hall, and then of
course you have Sindecuse. So, between the two buildings and the flagpoles, it
kind of gives me a sense of my bearings as far as the campus layout. And,
therefore, a sense of direction. I wouldn’t say the flagpoles are the most
prominent landmark on campus, but as far as student meetings and places it seems
to be centrally located so it is definitely a feature that students can identify with.

2) Um, we are going to Goldsworth Valley; there’s a pond and you go past
Sindecuse. There are buildings up here, so you know you’re heading in the right
direction. Yes (flagpoles are the prominent point on campus).

3) Buildings, trees, flagpoles.

In general, students identified the flagpoles as a prominent and focal point on campus.
It was determined by review of the transcript that 100% of the Geography 1900 students used the comparison mode, while 63% of the Geography 1900 students used the association mode in completing this reflective task (Figure 2).

Figure 2. Modes of Spatial Thinking Displayed (N=27).

Interview Item 3: “At this location, please identify one prominent landmark. (If answer is not flags, would you consider the flagpoles a prominent landmark? Describe the arrangement of the flagpoles relative to each other.”

The spatial mode Gersmehl (2008) identified as ‘pattern’ suggests that features are represented in clusters, strings, waves, or other non-random arrangements. Geography 1900 students commented:

1) Well, the flagpoles themselves form the shape of a triangle at their base as far as their actual layout. Um, the flagpoles all seem to be perpendicular to each other, or I’m sorry, parallel to each other in their height. I would assume there is a
triangle at the base. Each one is roughly 60 degrees in separation from the vertices of itself to the other two flagpoles.

2) There are clusters of three...there are three sets of three...it's like they make a triangle with the three flags. And they make a triangle with the sets of flags.

3) Uh, they're kind of set up in a triangle shape. Uh, they're probably about six feet from each other.

The geometric triangle is a recurring description in the conversation with the participants. The flagpoles are prominent on campus, and it was suggested that there are other prominent landmarks as well. These include the Echo Structure on campus, the WMU sign, and buildings such as Sangren Hall. Pattern was used within the interview conversation by thirty three (100%) Geography 1900 students as they referred to the arrangement of the flagpoles. This was expressed as a triangular pattern by these students. These students were using pattern a spatial modes of thinking as defined by Gersmehl (2008).

The spatial pattern for the base platforms for the flagpoles was also identified by six (22%) students. The comparison was used to describe and compare the flagpoles in terms of size, shape, and height. The flagpoles were also described by six (22%) students as being equal distant from each other. Students also used the comparison mode as they compared the flagpoles relative to each other in terms of size, shape, and height. The flagpoles were described in most instances as being equal distant from each other.

The association mode was reflected by many responses, as students associated in an example the same features with all flagpoles. The following is a transcript excerpt: “they are on a circular platform, the flags are the same height, and flags are equal distant from each other on the same platform.”
The association of all of these features in the same is a theme expressed by 52% of the Geography 1900 students in conversation. It was also determined that 100% of the students used the mode pattern, while 60% of the students used the mode comparison. The other modes of spatial thinking were not reflected (Figure 3).

Figure 3. Modes of Spatial Thinking Displayed (N=27).

*Interview Item 4: What direction are we presently walking? (Follow up) Are you relating this to anything else?*

Most of the students identified the direction as being north. Several students identified the direction as being south, east, or northeast. The relationship with direction and association with streets and highways is evident. A Geography 1900 student noted:

1) I would say we are headed pretty much due north, I would think, or in a northerly direction. Well, my reference points are pretty much extensive and expansive as far as just how my mind knows this is north. I know that W. Main runs east and west; I know Drake road runs north and south which is perpendicular to W. Main.
I also know that E. Michigan Avenue runs east and west which is again parallel to W. Main, perpendicular to Drake.

This student was making references to streets adjacent to campus. This is a mode of spatial thinking in making an association of direction with street orientations. This connection was quite common with all students. The category being exemplified in this question is the transportation systems: streets and highways. Other students determined the direction they were walking in relation to their residential location. By making these connections, a high percentage of students described an analogy in relating direction with other physical features or transportation routes became evident.

2) What direction are we currently heading? I’m going to say east, but I honestly don’t know. I’m trying to remember the way Westnedge runs, because I know Westnedge is behind us pretty much north. Westnedge is down that way and south is down the other way, so that would make us this way. But, I’m not actually sure if that’s right.

3) North. Well, I’m relating it to north because I know to my right is my hometown in that direction, and then South Haven is to the left.

It was determined through the Geography 1900 student transcripts that 85% of students used the analogy mode, while 30% of the students used the comparison mode. The other modes were not reflected in the conversations. The Geography 1900 students were using these modes of spatial thinking when relating the direction of travel to other geographic features and transportation routes (Figure 4).

At a specific location while walking downhill, I stopped and asked the student this question. The student generally took a few seconds to think about their response before answering. Most students responded in a fraction of a mile, in particular one quarter mile (0.25 mile). A majority of the Geography 1900 students answered one quarter of a mile
as the distance from Wood Hall to that point. There was general consistency within the answer. The approximate distance from Wood Hall to Interview Item 6 location as measured is 0.20 mile.

Figure 4. Modes of Spatial Thinking Displayed (N=27).

*Interview Item 5:* How far would you estimate we have walked since the beginning?

*Looking at the apartments below, what is the estimated distance from this location?*

The second interview item in this set asked the students to estimate the distance from the stopping point to the apartments in Goldsworth Valley. In most cases, the students identified a similar distance and stated that it was another quarter of a mile to the apartments. Other responses in distance clustered around one quarter of a mile.

*Interview Item 6:* Describe any changes in the route in this side of campus. Do you recall any Geography 1900 activities you may have applied?
Figure 5 shows a representation of the walk down Gilkison Avenue to Goldsworth Valley. Figure 6 shows the path of the walk down to Goldsworth Valley.

Figure 5. Map of Spatial Walk to Goldsworth Valley.

Figure 6. Interview Item 6 Location. Note: The downhill slope is shown in this photo.
Geography 1900 students commented:

1) Um it seems like we’re going *downhill* from where we started. Yeah, the um, when we had to draw the hill reminds me of Colorado, like how on one side you have, like the higher you go up a mountain, the higher, of course, the elevation; then weather’s going to change.

2) Well, we’ve gone *downhill*. It wasn’t a very steep hill, but elevation went lower. It seems like we’ve generally gone in the same direction. We’ve veered off a little to the left, but other than that we haven’t changed directions.

3) We’re going *downhill*. Yeah, we did like elevation, like highest and lowest points. Yeah, it was on a topographic map.

The identification of a change in slope or change in elevation was given in the answers by 93% percent of Geography 1900 students. They reflected that the walk gradually goes downhill during the latter half of the walk. Many students recognized this change. Although the actual word transition does not appear in the transcript, this is the mode of spatial thinking being exemplified. Other words noted by the participants such as, downhill and elevation change, suggest a reflection of the transition spatial mode of thinking (Table 2).

The transition mode of spatial thinking is where a change between two distinct spatial conditions is described. The change in elevation was noted by many of the students suggesting that transition was the spatial mode of thinking involved in their recognition of the changing conditions of elevation. Making the association with this gradual change in elevation and the topographic maps in the classroom were observed in the conversation.

It was determined after review of the conversations for Interview Item 6 that 100% of the Geography 1900 students used the mode transition, 93% used change, 8% of
the Geography 1900 students used the association mode, and 8% of the students used comparison. These modes of spatial thinking emerged from the dialogue as the end of the walk drew near (Figure 7).

![Spatial Walk: Interview Item 6](image)

Figure 7. Modes of Spatial Thinking Displayed (N=27).

**Interview Item 7: What content from your Geography 1900 course have you applied or thought about as we walked today?**

This question related to the content material of the Geography 1900 course and its application to real-world situations. When students are navigating, they are thinking spatially. Because the content of the course requires spatial ability, students were using the spatial applications they learned from the course. Maps were noted in the interviews since they are linked with direction, distance, and connections, students often noted this in their answers. Other answers were related to the weather. One Geography 1900 students commented:
1) We talked about all different kinds of things as far as, you know, precipitation and the fact that lower pressure systems seem to be more volatile and have an increase in chance in precipitation because as the warmer air is rising, it carries the moisture up to altitude which is obviously going the reach the dew point, the condensation point, and come back down. You know, there is so many different things about that and as far as lake effect snowfall; you know, obviously this wasn't snow we received today but if you watched the weather report it wasn't lake effect. It was probably enhanced slightly by lake effect, but the majority of it was just from the fact that we had a cold front from the north and we had a warm front from the south that came together and collided and provided that cold air mass as all the moisture which is why we got dumped on with 6 inches of snow today. Yeah, as far as the continental polar air mass coming out of the north and you have the maritime tropical masses – they tend to be warmer coming out of the Gulf of Mexico and combine right here in the Great Lakes region and obviously in the plain states as well. Anywhere, mid-continental is where that occurs...

2) Um, clouds. The weather part, I could tell it’s raining consistently kind of, and so I predict it will continue to rain at a consistent rate based on the way things are today. Um, we talked about precipitation in terms of the climate type, and so we receive rainfall here much more here than they would in the desert. Um, we talked about the cloud cover, and today would definitely be 100% cloud cover and the rain is part of that. It’s raining because the clouds are full of rain and water droplets. They had to release the water droplets because they’re too heavy.

3) Um, probably how the weather systems work. We learned how the pressure systems move in and out and what causes what type of weather, so I guess…we’re doing the weather journals, especially made me think about why we had the weather we have.

Students discussed the weather during the spatial walks, especially when the weather was unfavorable. Temperatures were occasionally quite cold and the students were cognizant of their discussions on temperature in the classroom activities. The most recent or activity for the concurrent week of the spatial walk was often discussed by the students. This interview item was the most dissimilar between the Geography 1900 and Geography 1020 students. The Atlas and map use in Geography 1020 was frequently
identified by Geography 1020 students. The following are selected excerpts from Geography 1020 students in response to this same interview item.

1) It taught me (Geography 1020 course) how to read a map better. Just to become more familiar with the world. Reading maps and being more familiar.

2) I guess the culture aspect; you can just look around campus and see all kinds of people.

3) Figuring out where to get to places.

The percentage of students who discussed a component of weather or an aspect of mapping was determined through the transcripts. This emerged as result of the many aspects of weather: temperature, precipitation, pressure, clouds, and wind studied in class. Students in Geography 1900 were often applying the concepts of weather lessons during the walks and recalling the activity completed in class.

The responses associated with the spatial walk were classified for a rational analysis. A review of Table 2 reveals the specific responses to the Interview Items. The following is a summary: 1) Students in the spatial walk experimental group were using objects in the environment as a reflection for spatial thinking. They cited buildings, flagpoles, etc; 2) they identified resources that would assist them in making spatial decisions and judgments, and 3) they conceptually, if not specifically, used language that was consistent with the modes of spatial thinking proposed by Gersmehl (2008).

In contrast, the comparison group had only eight students who participated in the spatial walk. There were no similar reflections regarding the concepts underlying spatial thinking. This suggests that the instruction in Geography 1900 invoked spatial thinking, but not the specific terminology, while that did not develop to the same extent among the
Geography 1020 students. Responses from the Geography 1020 group were generally brief in comparison with the Geography 1900 students. The sample of eight, however, reduces the confidence in this observation.

Common spatial modes and concepts of spatial thinking are presented in Table 4. These categories emerged as a result of the analysis of the transcripts for each interview item. The categories are resource, landmark, arrangement of flagpoles, direction of walk, distance, and change in route. Each one of these represents a link to spatial thinking during the spatial walk. The most common spatial modes of thinking during the walk were comparison, pattern, association, analogy, and transition.

Table 4: Common Mode/Concept of Spatial Thinking Associated with Spatial Walk Interview Items

<table>
<thead>
<tr>
<th>Interview Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Resource</td>
<td>Landmark</td>
<td>Arrangement of Flagpoles</td>
<td>Direction of Walk</td>
<td>Distance</td>
<td>Change in Route</td>
</tr>
<tr>
<td>Information and Common Response</td>
<td>Map; Compass; Left and Right</td>
<td>Buildings; Trees; Flagpoles; WMU Sign</td>
<td>Triangle; Circular Platform</td>
<td>North/Northeast</td>
<td>Quarter of a mile (0.25 mile)</td>
<td>Going Downhill; Landscape</td>
</tr>
<tr>
<td>Spatial Mode/Concept</td>
<td>Orientation</td>
<td>Comparison</td>
<td>Pattern, Association</td>
<td>Analogy</td>
<td>Spatial Relations</td>
<td>Transition</td>
</tr>
</tbody>
</table>

The data suggest that students use modes of spatial thinking outside the classroom as they move about campus and the environment. Perhaps the most obvious effect of spatial thinking is for route-learning and planning strategies.
Route-learning strategies are an important consideration because they impact performance, and considerable individual differences in preference and observed. Major strategies include the use of a cardinal reference system (i.e., compass points), turn-sequence memorization, and landmarks. Preferred landmarks may be proximal (set along one’s route) or distal (visible from a distance). (Lloyd, Persaud, & Powell, 2009, p. 424).

The qualitative data complemented the prior research (Lloyd et al., 2009), since compass points (North, South, etc.), and resulted in sequencing along the prescribed route, with proximal and distal landmarks on the Western Michigan University campus included in the range of verbal and physical behaviors exhibited by the students (Table 4).

Qualitative Analysis from Classroom Observations

Following the observations of the classroom and viewing of the video recordings, the rating by the trained observers and the researcher were analyzed. The complete list of activities observed during the Fall Semester 2008 and Spring Semester 2009 is presented in Appendix G. Observational notes made by the researcher during a five minute increment for every fifteen minutes is presented in Appendix H.

The spatio-temporal modes, movement and change, were strongly represented in the activities. The movement of the earth around the sun and seasonal change is an example of activities that concentrated on the spatio-temporal modes of movement and change. The concentration of the spatial mode, pattern, is exemplified in the Mapping II activity in which students view isohyets and draw in centers of atmospheric circulation. For the Mapping I activity, students draw isotherms and isobars. The topographic map
activity enables students to be actively engaged in making spatial connections between places. The following figures are examples of the assessment of the spatial modes in the Geography 1900 classroom activities as observed.

The modes of spatial thinking are clearly evident in the Geography 1900 activities observed. Students learn by visualization and observational tasks. The activities in Geography 1900 were designed to enable students to be actively engaged in the learning process. Students discover the concept and big ideas of earth science through these activities. Reviewing the video recording reveals active engagement in the activities and conversations within the groups of four students at individual tables.

The rating of the spatial modes of thinking were completed by in-class observations and viewing of video recording. The ratings were validated by two additional observers and having them rate a random selection of classes. The following graphs show the level of strength of each spatial mode of thinking in the activity. Seven Geography 1900 activities were observed during Fall Semester 2008 and Spring Semester 2009. Mapping II and Winds II were assessed from in-class observations along with two trained graduate colleagues and the researcher. The Length of Daylight and Sun Angle were the activities observed from a video recording inside the Mallinson Institute for Science Education Library. The identical co-observers assessed the modes of spatial thinking along with the researcher. Figures 2-4, 7 display the spatial modes of thinking for the corresponding Geography 1900 activity. Figures 8-14 represent the activities in which trained observers and the researcher made an assessment in-class or viewing the video tape.
One activity with substantial modes reflected was Mapping II. Mapping II activity required students to interpret annual precipitation in the world and identify locations of pressures cells with global circulation patterns. The most dominant spatial mode that is observed during the activity is pattern. The students discuss the patterns of regional rainfall in their groups. Additionally, movement of water and wind circulation were concepts strongly embedded in the activity. Students reflected on these concepts and spent the greatest amount of time on these related modes of spatial thinking. This activity requires drawing an isohyet (precipitation) map. The distribution of world precipitation within equatorial, tropical, temperate, and polar regions is an aspect of this activity. The students spent a great amount of time discussing these four climatic regions. Region is another strong mode of spatial thinking. The modes of spatial thinking observed in the seven activities are presented in Figures 8-14.

Students view topographic maps in the Topographic Map activity. A laminated map of Schoolcraft, Michigan was presented to the students at individual tables. An additional topographic map was presented in the syllabus activity. It was determined from the researcher’s observations that pattern and transition were greatly reflected in this activity.

The Length of Daylight activity required students to investigate how global surface temperatures vary with latitude and by season. Students viewed an interactive web page of the earth. Students updated a map by showing various times of the year indicating a difference view of daylight/darkness. Change is the spatial mode of thinking that is also exhibited during the activity and student conversations. Students viewed
change of daylight in seasonal dates. Other questions in the activity relate to the rotation of the earth.

![Figure 8](image)

Figure 8. Modes of Spatial Thinking Observed in the Topographic Map Activity, Direct Observation.

It was determined from the researcher’s and co-observers’ observations that movement and comparison were also strongly exhibited as students discussed the rotational movement of the earth and the comparison between northern and southern hemispheres. The remaining modes of spatial thinking are not strongly represented in this activity. The spatial modes of thinking observed in the Length of Daylight activity are presented in Figure 9.

The Sun Angle activity is an interactive exercise which began with an inflatable globe and flashlight. Students practiced a simulation of shining the flashlight on the table at different angles. The students simulated the earth revolving around the sun with the
inflatable globe. Students then reflected on the seasonal change pattern of surface temperatures and varying amounts of incoming radiation.

<table>
<thead>
<tr>
<th>Length of Daylight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
</tr>
<tr>
<td>Change</td>
</tr>
<tr>
<td>Association</td>
</tr>
<tr>
<td>Pattern</td>
</tr>
<tr>
<td>Analogy</td>
</tr>
<tr>
<td>Transition</td>
</tr>
<tr>
<td>Region</td>
</tr>
<tr>
<td>Comparison</td>
</tr>
</tbody>
</table>

*Figure 9. Modes of Spatial Thinking Observed in the Length of Daylight Activity, Co-observed (Video).*

It was determined from the researcher’s and co-observers’ observations that movement, change, and comparison are all greatly represented in this activity. Students described the movement of the earth rotating on its axis and revolving around the sun; the change in incoming radiation and surface temperatures were also discussed. During the seasonal model of the earth revolving around the sun, the students continuously compared the Northern and Southern Hemispheres in terms of daylight and temperatures. The spatial modes of thinking observed in the Sun Angle activity are presented in Figure 10.

In Mapping I, students drew isotherms and isobars. This activity greatly reflects the transition mode. Additionally, the association mode was reflected as students
discussed the pressure cells that correspond with the isobars. Pattern was greatly reflected as well when students discussed the shape of the lines.

![Sun Angle](image)

**Figure 10.** Modes of Spatial Thinking Observed in the Sun Angle Activity, Co-observed (Video).

Winds II is an activity that required students to discover the Coriolis effect through the inquiry-based investigation. Students placed a paper plate on a Lazy Susan and drew a line from the middle of the plate to the edge while the plate is rotating counter-clockwise. It was determined from the researcher’s observations that the greatest modes of spatial thinking emerging from the discussions were movement and pattern.

The students consistently discussed movement of wind, and this simulation is performed by drawing a line. Flow of wind, clockwise and counter-clockwise, is discussed during the entire activity. Association was another high frequency mode, as students associated high pressure with clockwise flow and low pressure with counter-
clockwise flow in the Northern Hemisphere. Precipitation was also associated with low pressure, while dry conditions were associated with high pressure. These concepts were discussed by the students in group work. The spatial modes of thinking observed in the Winds II activity are presented in Figure 12.

Figure 11. Modes of Spatial Thinking Observed in the Mapping I Activity, Direct Observation.

Mapping II is an activity that required students to assess for precipitation, global circulation and wind patterns. Mapping II modes of spatial thinking are presented in Figure 13. Pattern was the greatest mode of spatial thinking as the discussions and interactions between students were related to wind flow. The association of precipitation, low pressure, and wind flow was identified by many students in their discussions.
The Lake Effect activity was the final observation during Fall Semester 2008 and Spring Semester 2009. After review of the observations and discussions within the classes, it was determined that association and comparison were greatly reflected.

Figure 12. Modes of Spatial Thinking Observed in the Winds II Activity, Direct Observation.

Figure 13. Modes of Spatial Thinking Observed in the Mapping II Activity, Direct Observation.
Students discussed the association of cold air, warm water, wind direction, clouds, and snowfall. It was determined from the researcher’s and co-observers’ observations that students compared different areas and locations of Michigan in terms of snowfall. Figure 14 presents the spatial modes of thinking observed in the Lake Effect activity.

![Lake Effect Diagram](image)

*Figure 14. Modes of Spatial Thinking Observed in the Lake Effect Activity, Direct Observation.*

**Quantitative Analysis of the Spatial Thinking Test**

The analysis of the pre-post tests was used to determine any significant differences between the three groups: Geography 1900, Geography 1020, and KVCC earth science. A total of two hundred ninety students participated in the Fall 2008 and Spring 2009 combined semesters. The analysis for each semester is presented separately followed by analysis combining all students who responded to both the pre and post
assessments of spatial thinking. The paired samples t-test requires that both the pre and post tests be used for all students.

Nineteen total spatial tasks were included in the pre and post-tests. It was determined that one item (items #10 pre-test, #19 post-test excluded from analysis) would not be evaluated due to the extremely subjective nature of the one item; eighteen items were evaluated on the pre-test, and eighteen items were evaluated on the post-test in the analysis for Fall Semester 2008 and Spring Semester 2009. The pre and post-tests are included in Appendix N. The post-test included a water glass item that is similar to an example from Piaget (Piaget & Inhelder, 1956). A do not know option was included. For the purposes of the within group and between group analyses, a dichotomy scheme was devised such that all answers indicated as do not know were determined to be incorrect. An item analysis of Fall Semester 2008 scores, which includes all three options on the Spatial Thinking Test, is represented in Appendices J, K, and L.

When scoring the tests, the number correct out of eighteen was recorded. The statistical program used for the analysis in calculating the Paired Samples t-tests and Analysis of Variance (ANOVA) was SPSS (2003). These testing procedures were used to determine whether there were statistically significant differences on mean scores between and within the experimental and comparison groups.

The following tables and figures present the analysis of the pre and post tests and the Paired Samples t-tests for the experimental Geography 1900, the comparison Geography 1020, and the experimental KVCC groups. An Analysis of Variance was used to assess for any statistical differences between groups.
Geography 1900 Students: Fall Semester 2008

The following table represents paired samples statistics for the experimental group during Fall Semester 2008 Geography 1900 course (Table 5) (Appendices J, K).

Table 5: Pre to Post Paired Samples Descriptive Statistics for the Geography 1900 Students in Fall Semester 2008

<table>
<thead>
<tr>
<th>Pair</th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1900PRE</td>
<td>61.4419</td>
<td>43</td>
<td>13.1571</td>
<td>2.0064</td>
</tr>
<tr>
<td>G1900PST</td>
<td>65.5581</td>
<td>43</td>
<td>18.0743</td>
<td>2.7563</td>
</tr>
</tbody>
</table>

The experimental group scores on the Spatial Thinking Test from Geography 1900 (Fall Semester 2008) were analyzed using the Paired Samples t-test (Table 6).

Table 6: Pre to Post-Test Paired Samples T-Test for Geography 1900 Students in Fall Semester 2008

<table>
<thead>
<tr>
<th>Paired samples mean</th>
<th>Mean Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4.1163</td>
<td>14.8006</td>
<td>2.2571</td>
<td>-1.824</td>
<td>42</td>
<td>.075*</td>
</tr>
</tbody>
</table>

*Statistically not significant

Geography 1020 Students: Fall Semester 2008

The following table represents descriptive statistics for the pre to post test comparison group scores for students in the Fall Semester 2008 Geography 1020 course (Table 7).
Table 7: Pre to Post Paired Samples Descriptive Statistics for the Geography 1020 Students in Fall Semester 2008

<table>
<thead>
<tr>
<th>Pair</th>
<th>G1020PRE</th>
<th>79</th>
<th>14.1515</th>
<th>1.5922</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 G1020PST</td>
<td>66.2658</td>
<td>79</td>
<td>13.8561</td>
<td>1.5589</td>
</tr>
</tbody>
</table>

The comparison group scores on the Spatial Thinking Test from Geography 1900 (Fall Semester 2008) were analyzed using the paired samples t-test (Table 8).

Table 8: Pre to Post Paired Samples T-Test for the Geography 1020 Students in Fall Semester 2008

<table>
<thead>
<tr>
<th>Paired samples mean</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4.1392</td>
<td>11.6407</td>
<td>1.3097</td>
<td>-3.160</td>
<td>78</td>
<td></td>
<td>.002*</td>
</tr>
</tbody>
</table>

* Statistically significant at the 95% confidence level

KVCC Students: Fall Semester 2008

The following tables represent paired samples statistics for the pre to post-test scores for students in the Fall Semester 2008 KVCC earth science course (Table 9).

Table 9: Paired Samples Descriptive Statistics for the KVCC Students in Fall Semester 2008

<table>
<thead>
<tr>
<th>Pair</th>
<th>KVCC_PRE</th>
<th>16</th>
<th>12.3381</th>
<th>3.0845</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 KVCC_PST</td>
<td>64.5625</td>
<td>16</td>
<td>14.5004</td>
<td>3.6251</td>
</tr>
</tbody>
</table>
The experimental group scores on the Spatial Thinking Test from KVCC earth science (Fall Semester 2008) were analyzed using the Paired Samples t-test (Table 10).

Table 10: Pre to Post Paired Samples T-Test for the KVCC Students in Fall Semester 2008

<table>
<thead>
<tr>
<th>Paired samples mean</th>
<th>Mean Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.8750</td>
<td>10.8927</td>
<td>2.7232</td>
<td>-2.157</td>
<td>15</td>
<td>.048*</td>
</tr>
</tbody>
</table>

*Significance at the 95% confidence level

Fall Semester 2008 Pre-Post Test Analysis Summary

The paired samples t-tests is a statistical method to determine differences between means, and in this research, the mean scores of the pre- and post-tests for the experimental and comparison groups. The mean within group pre-test scores for each of the groups on the Spatial Thinking Test were analyzed by comparing the means for statistically significant differences.

The Geography 1020 scores were statistically significant from pre to post, while the Geography 1900 scores were not statistically significant from pre to post. The mean pre-test score for the Geography 1900 students was 61.4 with a standard deviation of 13.2 (Table 6). The mean score for the Geography 1020 students was 62.1 with a standard deviation of 14.2 (Table 7). In the KVCC group, a mean score of 58.7 was calculated with a standard deviation of 12.3 (Table 9).

The One-way analysis of variance (ANOVA) results suggests no statistically significant differences between the pre-test mean scores for the experimental, comparison
and KVCC groups. The p-value of the ANOVA is presented in Table 9 (.656). No additional statistical tests were required, as the One-way ANOVA verified there were no statistically significant differences between the three groups (Table 11).

Students began each of the classes with similar predisposition to think spatially as indicated by the pre-test scores. No statistically significant differences were identified between the three groups on the pre-test.

Table 11: One-way ANOVA of the Pre-Tests for all Three Groups (Geography 1900, Geography 1020, and KVCC) (PRE08)

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>157.695</td>
<td>2</td>
<td>78.847</td>
<td>.423</td>
<td>.656</td>
</tr>
<tr>
<td>Within Groups</td>
<td>25174.776</td>
<td>135</td>
<td>186.480</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>25332.471</td>
<td>137</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Paired Samples t-test also revealed which of the, Fall Semester 2008 groups demonstrated a statistically significant differences between their pre and post-tests. The paired samples t-test produced statistically significant differences within the Geography 1020 group and the KVCC group. The respective p-values were 0.048 and 0.002. The p-value for Geography 1900 students was 0.075. The null hypothesis of equal means can be retained for the experimental group in the Spatial Thinking Test for Fall Semester 2008. The post-value scores for the Geography 1900, Geography 1020, and KVCC earth science all increased from pre to post-test. These data thus suggest that the coursework
provided a basis for students to improve their spatial thinking as measured by the Spatial Thinking Test.

As indicated prior to the beginning of this research, Gersmehl’s (2008) modes of spatial thinking are embedded in the Geography 1900 syllabus. The rationale why the pre-post test scores did not reveal statistical significance can be explained in several ways. First, the p-value of .075 may be justified as significant in educational, social and quasi-experimental research (Campbell & Stanley, 1963). The researcher has established .05 as the alpha level and thus the difference in means was rejected. Other than the pre-tests, no other questionnaire was used in determining student pre-knowledge and ability to think spatially, so there was no contamination of the group with prior knowledge that would have provided a higher pre-test mean. Students in Geography 1900 during the Fall Semester 2008 may have had demonstrated a predisposition to think spatially on the pre-test that was not enhanced by their coursework. No questionnaires were distributed to the students prior to the administering of the pre-tests. The post-test scores did improve for all three groups: Geography 1900, Geography 1020, and KVCC.

The underlying theory of this research is that positive changes in student behavior can be attributed to course materials and methodology. Additionally, instructional style can be a factor in learning. Each of the groups experienced one of two different teaching methodologies: inquiry-based laboratory and traditional lecture and each succeeded in raising post-test scores. The post-test spatial tasks were identical with the pre-test except that the sequence of items was altered.

Differences between the pre to post test scores were calculated using the One-way Analysis of Variance (ANOVA) to determine whether any significant differences were
observed between scores (post minus pre) of the three groups. The between groups statistical analysis suggested that there was no statistically significant difference between the post-test improvement in scores on the spatial thinking test for the experimental and comparison groups. The p-value was .883 ≥ .05, therefore the null hypothesis of no significant differences can be retained (Table 12).

A One-way Analysis of Variance (ANOVA) test was conducted on mean post minus pre-test values for all three groups. The analysis suggested no statistical significant differences. The greatest change between the mean values of the pre and post-test scores occurred in the KVCC experimental group. The p-value at .883 (≥.05) suggesting that there are no statistically significant differences within the pre to post test scores when the mathematical difference is applied to the analysis among the three groups (Table 12).

Table 12: One-way Analysis of Variance (ANOVA) for the Pre to Post Differences (Post minus Pre) for Geography 1900, Geography 1020, and KVCC in Fall Semester 2008 (PSTPRE08)

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>40.419</td>
<td>2</td>
<td>20.210</td>
<td>.125</td>
<td>.883</td>
</tr>
<tr>
<td>Within Groups</td>
<td>21868.660</td>
<td>135</td>
<td>161.990</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21909.080</td>
<td>137</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The descriptive statistics identifies the differences (post minus pre) for the mean scores on the Spatial Thinking Test during Fall Semester 2008 (Table 13). The groups are the following: 1) Geography 1900 students; 2) Geography 1020 students; and 3) KVCC
students. The data informed the researcher about the following. The mean differences between post and pre were highest in the KVCC students, while the smallest difference occurred in the Geography 1020 class. The greatest standard deviation was 15.0550 with the Geography 1900 students. It is noted with the negative difference that some students decreased their score between the pre and post-tests. Most students did increase their scores from pre to post as indicated in the positive mean value for all three groups. These statistics suggest that spatial thinking is incorporated in the content of each course.

Descriptive data is presented between the students in Geography 1900, Geography 1020, and KVCC (Table 13).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>95% Confidence Interval for Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower Bound</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Upper Bound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>43</td>
<td>4.3256</td>
<td>15.0550</td>
<td>2.2959</td>
<td>-3.077</td>
<td>8.9588</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>79</td>
<td>4.1392</td>
<td>11.6407</td>
<td>1.3097</td>
<td>1.5319</td>
<td>6.7466</td>
<td>-21.00</td>
</tr>
<tr>
<td>3.00</td>
<td>16</td>
<td>5.8750</td>
<td>10.8927</td>
<td>2.7232</td>
<td>7.071E-02</td>
<td>11.6793</td>
<td>-11.00</td>
</tr>
<tr>
<td>Total</td>
<td>138</td>
<td>4.3986</td>
<td>12.6460</td>
<td>1.0765</td>
<td>2.2699</td>
<td>6.5272</td>
<td>-28.00</td>
</tr>
</tbody>
</table>

Pre and Post Test Analysis: Spring Semester 2009 Geography 1900

The scores on the Spatial Thinking Test were analyzed for two groups during Spring Semester 2009: Geography 1900 and Geography 1020. The KVCC class did not participate due to course schedule and teaching times. Three Geography 1900 sections
were grouped for analysis purposes. The number of students in the combined Geography 1900 classes was 61 during the Spring Semester 2009, compared to 41 than Fall Semester 2008.

There was a statistically significant difference between the pre and post mean scores for Geography 1900 on the spatial thinking test. The p-value for the paired samples t-test was statistically significantly (≤.05) in a positive direction. The post-test mean was greater numerically than the pre-test mean. The data suggest that the Geography 1900 experimental group improved their spatial thinking.

The following tables represent paired samples statistics for the pre to post-test scores for students in the Spring Semester 2009 Geography 1900 course (Table 14).

<table>
<thead>
<tr>
<th>Pair</th>
<th>PRE19009</th>
<th>PST19009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>55.4426</td>
<td>62.8852</td>
</tr>
<tr>
<td>N</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>14.7326</td>
<td>17.2144</td>
</tr>
<tr>
<td>Std. Error Mean</td>
<td>1.8863</td>
<td>2.2041</td>
</tr>
</tbody>
</table>

Pre to post-test mean scores for the experimental group on the Spatial Thinking Test for Geography 1900 (Spring Semester 2009) were analyzed using the Paired Samples t-test (Table 15).

A statistically significant difference between pre and post-tests was observed from the paired samples t-test. A p-value of .000 (≤.05) for a confidence level of 95% or higher was suggested. The mean scores for the pre-tests were lower in the Spring Semester 2009
than in Fall Semester 2008, although the difference between post and pre-tests was greater.

Table 15: Pre to Post Paired Samples T-Test for the Geography 1900 Students in Spring Semester 2009

<table>
<thead>
<tr>
<th>Paired samples mean</th>
<th>Mean Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7.4426</td>
<td>13.3959</td>
<td>1.7152</td>
<td>-4.339</td>
<td>60</td>
<td>.000*</td>
</tr>
</tbody>
</table>

*Significance at the 95% confidence level

Geography 1020 Students: Spring 2009 Semester

The pre to post-test mean scores on the Spatial Thinking Test was statistically significant for the Geography 1020 comparison group as well.

The map analysis and extensive atlas use in Geography 1020 may have contributed to the improved mean scores. The Geography 1900 syllabus activities were not the experimental treatment, but the atlas use may have affected spatial thinking in similar ways using quite different classroom methodologies.

The following tables represent paired samples statistics for the pre to post-test scores for students in the Spring 2009 Geography 1020 course (Table 16). The comparison group mean scores on the spatial thinking test from Geography 1020 were analyzed using the Paired Samples t-test (Table 17).

Table 16: Pre to Post Paired Samples Descriptive Statistics of the Geography 1020 Students in Spring Semester 2009

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair G1020PRE</td>
<td>57.8132</td>
<td>91</td>
<td>14.9762</td>
<td>1.5699</td>
</tr>
<tr>
<td>2 G1020PST</td>
<td>61.6923</td>
<td>91</td>
<td>16.3793</td>
<td>1.7170</td>
</tr>
</tbody>
</table>
Table 17: Pre to Post Paired Samples T-Test for the Geography 1020 Students in Spring Semester 2009

<table>
<thead>
<tr>
<th>Paired samples mean</th>
<th>Mean Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.8791</td>
<td>14.8951</td>
<td>1.5614</td>
<td>-2.484</td>
<td>90</td>
<td>.015*</td>
</tr>
</tbody>
</table>

*Significance at the 95% confidence level

An Independent Sample t-test was used to determine if there were statistically significant differences between the post and pre-test mean scores of the Spring Semester 2009 experimental and comparison groups. An independent was used. There were no statistically significant differences between the two groups on either test. Independent Samples t-tests comparing the differences with means of the pre-tests and post-tests (post minus pre) between the Geography 1900 and Geography 1020 students is presented in Table 18.

The data and their analysis suggest there was no statistically significant difference between the pre-test scores between the experimental and comparison groups. However, the experimental group did demonstrate a higher group mean score than the comparison group.

Table 18: Analysis of Spring Semester 2009 Geography 1900 and 1020 Students (group 1.00) and Geography 1020 Students (group 2.00) Difference (Post minus Pre)

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geog 1900</td>
<td>61</td>
<td>6.7213</td>
<td>13.7782</td>
<td>1.7641</td>
</tr>
<tr>
<td>Geog 1020</td>
<td>91</td>
<td>3.2637</td>
<td>15.0435</td>
<td>1.5770</td>
</tr>
</tbody>
</table>
Table 19: Independent Samples T-Test of Pre to Post Changes (Post minus Pre) in Spatial Thinking Test Score Means (Geography 1900 and Geography 1020) in Spring Semester 2009

<table>
<thead>
<tr>
<th>Mean Difference</th>
<th>Std. Error Difference</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4567</td>
<td>2.4078</td>
<td>1.436</td>
<td>150</td>
<td>.153*</td>
</tr>
</tbody>
</table>

* Not statistically significant

Table 20: Spring Semester 2009 Geography 1900 (1.00) and Geography 1020 (2.00) Pre-Test Descriptive Statistics

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geog 1900</td>
<td>61</td>
<td>55.4426</td>
<td>14.7326</td>
<td>1.8863</td>
</tr>
<tr>
<td>Geog 1020</td>
<td>91</td>
<td>57.8132</td>
<td>14.9762</td>
<td>1.5699</td>
</tr>
</tbody>
</table>

Table 21: Independent Samples T-Test of Pre-Test Mean Scores between Geography 1900 and Geography 1020 Spring Semester 2009

<table>
<thead>
<tr>
<th>Mean difference</th>
<th>Std. Error difference</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.3706</td>
<td>2.4622</td>
<td>-.963</td>
<td>150</td>
<td>.337*</td>
</tr>
</tbody>
</table>

*Not statistically significant

Fall 2008 and Spring 2009 Geography 1900 Pre to Post-test Analysis

Paired Samples t-test was used to determine whether statistically significant differences exist from pre to post for the Fall Semester 2008 and Spring Semester 2009 of a combined experimental group of one hundred and four Geography 1900 students (Table 22). The test revealed statistically significant increased between the pre to post-tests.
The data lead the researcher to accept that the experimental treatment had a positive and statistically significant effect on the spatial thinking of Geography 1900 students as measured by the Spatial Thinking Test. Hypothesis 2 is accepted.

Table 22: Pre to Post Paired Samples Statistics for the Geography 1900 Students in Fall Semester 2008 and Spring Semester 2009

<table>
<thead>
<tr>
<th>Pair</th>
<th>PRE1900</th>
<th>PST1900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>57.9231</td>
<td>63.9904</td>
</tr>
<tr>
<td>N</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>14.3471</td>
<td>17.5380</td>
</tr>
<tr>
<td>Std. Error Mean</td>
<td>1.4068</td>
<td>1.7197</td>
</tr>
</tbody>
</table>

Table 23: Pre to Post Paired Samples T-Test for Geography 1900 Students in Fall Semester 2008 and Spring Semester 2009

<table>
<thead>
<tr>
<th>Paired samples mean</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-6.0673</td>
<td>14.0203</td>
<td>1.3748</td>
<td>-4.413</td>
<td>103</td>
<td>.000*</td>
</tr>
</tbody>
</table>

*Significance at the 95% confidence level

The following tables represent the differences (post minus pre) for the entire sample of students, Fall Semester 2008 and Spring Semester 2009. In order to examine the change in pre to post-test scores on the Spatial Thinking Test, the researcher determined the difference in pre-post scores (post-test minus post-test) for the experimental, comparison, and KVCC group. The difference between the pre to post mean group scores were listed for significance of difference between groups using the One-way Analysis of Variance (ANOVA). The descriptive statistics are presented in
Table 24. The ANOVA statistic suggested there was not a statistically significant difference for the pre to post-tests between groups (Table 25).

Table 24: Descriptive Data between the Percentage Differences (Post minus Pre) of the Three Groups in Fall Semester 2008 and Spring Semester 2009 [Geography 1900 (group 1), Geography 1020 (group 2), and KVCC (group 3)] (PSTPRE)

<table>
<thead>
<tr>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>95% Confidence Interval for Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower Bound</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Upper Bound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>104</td>
<td>5.7308</td>
<td>14.2973</td>
<td>1.4020</td>
<td>-28.00</td>
<td>44.00</td>
</tr>
<tr>
<td>2.00</td>
<td>170</td>
<td>3.6706</td>
<td>13.5371</td>
<td>1.0382</td>
<td>-39.00</td>
<td>45.00</td>
</tr>
<tr>
<td>3.00</td>
<td>16</td>
<td>5.8750</td>
<td>10.8927</td>
<td>2.7232</td>
<td>-11.00</td>
<td>28.00</td>
</tr>
<tr>
<td>Total</td>
<td>290</td>
<td>4.5310</td>
<td>13.6830</td>
<td>.8035</td>
<td>-39.00</td>
<td>45.00</td>
</tr>
</tbody>
</table>

Table 25: One-way Analysis of Variance (ANOVA) for the Differences (Post minus Pre) for Three Groups (Geography 1900, Geography 1020, and KVCC) in Fall 2008 Semester and Spring Semester 2009 (PSTPRE)

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>304.456</td>
<td>2</td>
<td>152.228</td>
<td>.812</td>
</tr>
<tr>
<td>Within Groups</td>
<td>53803.764</td>
<td>287</td>
<td>187.470</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54108.221</td>
<td>289</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figures 15-17 represent the Scatter Plots of the Spatial Thinking Test for the Geography 1900, Geography 1020, and KVCC Sample. While there was an overall increase in scores from pre to post-tests, some students did receive lower scores. Multiple scores were placed on single plots, indicating that some individuals had identical scores on Pre and Post of the Spatial Thinking Test.

Figure 15. Scatter Plot of Spatial Thinking Test for the Geography 1900 Sample.

An Analysis of Covariance (ANCOVA) was used to test the accumulated data. The purpose of the ANCOVA is to analyze and assess the effects of post test performance based on pre-test scores. The ANCOVA is a commonly used statistic when prior knowledge, particular skills, and other abilities are not within the control of the researcher in the sample selection.
Figure 16. Scatter Plot of Spatial Thinking Test for the Geography 1020 Sample.

Figure 17. Scatter Plot of Spatial Thinking Test for the KVCC Sample.
For the current research, ANCOVA was a second analytical test of the data to identify differences between the experimental and comparison groups on the post administration of the Spatial Thinking Test. Table 26 presents the descriptive statistics of the group means of the accumulated Post-tests for Geography 1900, Geography 1020, and KVCC. Table 27 shows the effects of post-test performance based on pre-test scores. The obtained p-value .000 suggested a significant difference in the pre to post tests scores both within and between groups when the pre-test score was used as a covariate.

Table 26: Descriptive Data of the Post-Test Group Means for (Geography 1900 (1), Geography 1020 (2), and KVCC (3) (Dependent Variable: POSTTEST)

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>63.9904</td>
<td>17.5380</td>
<td>104</td>
</tr>
<tr>
<td>2.00</td>
<td>63.8176</td>
<td>15.3856</td>
<td>170</td>
</tr>
<tr>
<td>3.00</td>
<td>64.5625</td>
<td>14.5004</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>63.9207</td>
<td>16.0933</td>
<td>290</td>
</tr>
</tbody>
</table>

Table 27: ANCOVA Test Statistic for Accumulated Pre to Post Data for the Three Groups: Geography 1900, Geography 1020, and KVCC

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>28229.964a</td>
<td>3</td>
<td>9409.988</td>
<td>57.728</td>
<td>.000</td>
</tr>
<tr>
<td>Intercept</td>
<td>8564.347</td>
<td>1</td>
<td>8564.347</td>
<td>52.541</td>
<td>.000</td>
</tr>
<tr>
<td>PRETEST</td>
<td>28221.063</td>
<td>1</td>
<td>28221.063</td>
<td>173.131</td>
<td>.000</td>
</tr>
<tr>
<td>GROUP</td>
<td>153.055</td>
<td>2</td>
<td>76.528</td>
<td>.469</td>
<td>.626</td>
</tr>
<tr>
<td>Error</td>
<td>46619.212</td>
<td>286</td>
<td>163.004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1259747</td>
<td>290</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>74849.176</td>
<td>289</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analysis: Hypotheses Testing

Hypothesis 1: Geography 1900 has clearly identifiable modes of spatial thinking embedded within the earth science content.

At the beginning of the Fall Semester 2008, the researcher and a recent doctoral graduate evaluated seven different activities for embedded modes of spatial thinking (Gersmehl, 2008). It was concluded that Gersmehl’s modes of spatial thinking were indeed embedded within the course activities for Geography 1900. The activities were further assessed to identify where modes of spatial thinking would likely be required to solve problems and complete the map analysis that were incorporated. From the eleven spatial modes, including the spatio-temporal modes, eight modes including comparison, analogy, region, association, pattern, transition, change, and movement were identified as being embedded in at least one or more of the activities reviewed (Appendix D). Hypothesis 1 was accepted based on empirical evidence.

Hypothesis 2: Students apply specific modes of spatial thinking before instruction as measured by the Spatial Thinking Test.

Results: Hypothesis 2 was accepted. The Spatial Thinking Pre-Test scores suggest spatial thinking was applied by students at the beginning of the Geography 1900 experimental treatment.

Hypothesis 3: Modes of spatial thinking by students in Geography 1900 will significantly improve as a result of their completion of the course.
Results: The completion of the pre and post-tests is a commonly accepted means to ascertain if significant improvement for students undergoing a treatment has changed their knowledge level or behavior. Students who completed both the pre and post-tests were evaluated for this research. A smaller portion of students did not complete both the pre- and post-tests and were eliminated from the research. The tests were administered to the Geography 1900 students in Fall Semester 2008 and Spring Semester 2009. Statistical analyses including the Paired Samples t-test and ANOVA statistical analysis were used.

Hypothesis 3 is rejected for the Fall Semester 2008 students, yet accepted for the Spring Semester 2009 students. The Geography 1900 students in Fall Semester 2008 did not statistically improve their scores; however, the Geography 1900 students did statistically improve their scores from the pre and post-tests in Spring Semester 2009. Hypothesis 3 is accepted for the combined semesters of Geography 1900 students. A statistically significant improvement from pre to post was identified for the full Geography 1900 group.

Hypothesis 4: Geography 1900 will have a positive effect on the spatial thinking of a majority of students.

Results: Hypothesis 4 was rejected for Fall Semester 2008, since 49% of students improved from pre to post. Hypothesis 4 was accepted for Spring Semester 2009, since 67% of students improved from pre to post; Hypothesis 4 was accepted for combined Fall Semester 2008 and Spring Semester 2009 groups (62 out of 104: 60%) based on the modest number of students who improved. A significant change was observed by virtue of improved student scores from pre to post mean scores (Spring Semester 2009 and
combined semesters) on the Spatial Thinking Test as well as the occurrence of verbal reflections observed in the classroom and on the spatial walk that were conceptually referenced to the modes of spatial thinking.

_Hypothesis 5: Students apply modes of spatial thinking in their activities outside the classroom as indicated during a spatial walk._

Students used modes of spatial thinking during their spatial walk outside of the classroom. The evidence from the transcripts audio recorded suggests that Gersmehl’s (2008) modes of spatial thinking were applied by the students. The percentages of students using the modes of spatial thinking related to the interview items were identified earlier in Figures 2-4, 7. Hypothesis 4 is accepted based on the qualitative evidence from spatial walks.

_Hypothesis 6: Students completing Geography 1900 will demonstrate greater increases in spatial thinking compared to students in the Geography 1020 comparison group._

Results: Geography 1020 students in the world regional geography class served as the comparison group. The pre and post-tests were evaluated and compared with the mean scores from the Geography 1900 class. Students in Geography 1020 did improve their modes of spatial thinking as indicated by the pre to post-test mean scores in the Spatial Thinking Test. There was an increase in mean scores between pre and post-tests for the comparison group.

The Geography 1020 students improved significantly mean scores on the Spatial Thinking Test during both semesters, Fall Semester 2008 and Spring Semester 2009. The
Geography 1900 students improved mean scores on the post-tests for both semesters, although the Fall Semester 2008 group did not have a statistically significant increase.

Hypothesis 6 is rejected, because the statistical tests revealed no significant differences between the experimental group Geography 1900 and the comparison group Geography 1020. Both groups increased their mean score performance of the Spatial Thinking Test.

Qualitative and Quantitative Data Comparisons

Identifying the relationship between the qualitative and quantitative data is important in the analysis of spatial thinking. The qualitative relationship between the two data sets that were collected in the research were analyzed. The improved scores between pre and post-tests suggest that students both learned and improved their applications of thinking spatially in Geography 1900, Geography 1020, and KVCC earth science. Students who participated in spatial walk were reflective in the applications of the spatial thinking modes of pattern, comparison, association, and transition.

Analysis of the qualitative and quantitative data from both observations of classes suggested that modes of spatial thinking were important parts of the course. However, do the two data sets complement each other? In order to answer that question, the researcher reviewed the responses that represented pattern, comparison, association, analogy, and transition.

Pattern was observed as a mode of spatial thinking in the classroom observations, spatial walk, and Spatial Thinking Test. The use of this mode was evident in the Geography 1900 experimental group student interactions through the discussion of wind
flow patterns around atmospheric high and low pressures in Winds II as an example.

During the spatial walk the students applied the modes of pattern in the following ways. Students described the arrangement of the flagpoles and platform in terms of geometric shapes. Pattern was reflective in the drawing of contour lines and recognition of precipitation pattern in the Texas item of the Spatial Thinking Test.

Comparison was observed as a mode of spatial thinking in the classroom observations, spatial walk, and Spatial Thinking Test. The use of this mode was evident in the student interaction and discussion of the Northern Hemisphere and Southern Hemisphere comparison in the Length of Daylight activity. The use of this mode was evident in the student comparison of landmarks and buildings with direction and orientation. Comparison was reflective in the comparison of geometric shapes in these items of the Spatial Thinking Test.

Association was observed as a mode of spatial thinking in the classroom observations, spatial walk, and Spatial Thinking Test. The use of the mode was evident in the student interactions of several activities. As an example, in the Lake Effect activity students associated cold air, low pressure, warm water and wind direction with this snow process. An association was evident in topographic map on the Spatial Thinking Test. Students associated the features of the flagpoles (arrangement, circular platform, and most prominent landmark on campus).

Analogy was observed as a mode of spatial thinking in the classroom observations, spatial walk and Spatial Thinking Test. Analogy was observed in the Lake Effect activity as students discussed other similar location (with West Michigan that experience this process. Analogy was recalled as students developed an analogy of their
direction of walk with their apartments. Analogy is reflected on the climate example as an example on the Spatial Thinking Test.

Transition was observed as a mode of spatial thinking in the classroom observations, spatial walk and Spatial Thinking Test. Transition was observed in the Mapping I activity as students discussed transitions and change between intervals of isotherms/isobars. Transition was cited (although not the word specifically) by students as a change in elevation or downslope during the walk. Transition was reflected in the topographic map and the contour lines as examples in the Spatial Thinking Test.

Future research can expand on the modes of spatial thinking that were investigated to validate their applications in the earth science classrooms. The application of concepts learned in class and applied as modes outside the classroom is a reserved topic of importance. Such evidence may also provide evidence of elementary school students' development of spatial thinking.

Spatial thinking may be assessed in multiple ways. The three types that were assessed in this study include pre-post tests, spatial walks, and classroom observations. Students demonstrated spatial thinking in their spatial walks and the spatial thinking test. Gersmehl's (2008) modes of spatial thinking were reflected by the student interviews and performance on spatial test items. Of the students who demonstrated the use of modes of spatial thinking on the spatial walk, approximately 88% also had an improvement of their scores on the spatial thinking test.

Analysis of the data collected suggested that students used spatial thinking in their classroom activities as well as during the outside walks. This study and future research will serve to promote a science curriculum that includes spatial thinking. Pre-service
elementary teacher education students with spatial thinking skills will influence children to develop similar spatial thinking concepts and modes of spatial thinking. Students at young ages should be taught to think spatially and continue to apply those modes.
CHAPTER V

DISCUSSION OF RESULTS

The Research Questions

This discussion is a comprehensive review of the research questions presented at the beginning of this study. Following the collection, analysis, and presentation of the qualitative and quantitative data, results emerged. The researcher subjected the results to critical analysis. The researcher concludes that spatial thinking is an important skill that is learned and applied in the earth sciences. Learning to think spatially benefits students in learning earth science content as well as performing tasks in everyday life. These tasks in everyday life include navigation and route-planning. The original research questions from which the hypotheses were derived will serve as the basis for the discussion of results.

1. **What modes of spatial thinking did students apply at the beginning of Geography 1900 course?**

The modes of spatial thinking that students applied at the beginning of the Geography 1900 course were assessed using the pre-test of spatial thinking. Eighteen spatial items were included on the pre-tests, and eighteen items were evaluated (Appendix N). The items were evaluated and converted into a percentage. Students demonstrated their spatial thinking skills by responding to tasks requiring them
to use spatial modes. The spatial thinking test assessed the modes identified by Gersmehl (2008). Data from the spatial thinking test were compared for the experimental and comparison groups. Results suggest that there are no statistically significant differences between pre-tests of the experimental and comparison groups. The six core modes of spatial thinking on the pre-tests were: comparison, region, transition, analogy, pattern, and association (Gersmehl, 2008). At the beginning of the Geography 1900 course the mean score on the spatial thinking test was 61.4 and 55.4, respectively for Fall Semester 2008 and Spring Semester 2009. The core modes that were greatly reflected in the pre-tests were comparison, pattern, transition, and association. These modes were reflected in the high evaluation scores of mental rotation and shape examples (comparison), the Texas precipitation (pattern, transition), and the topographic map (association and transition). The average percentage score for these examples was over 75%. Item assessment of pre-tests for Fall 2008 Semester Geography 1900 students is indicated in Appendices J (A.), K (A.).

2. What spatial thinking modes were embedded in the Geography 1900 course based on the Gersmehl (2008) classification?

The modes of spatial thinking that were embedded in the syllabus. Through an analysis of the syllabus activities, it was revealed that the modes are embedded within the activities in addition to spatio-temporal modes. Six of the eight core modes of spatial thinking were strongly reflective in the syllabus along with two of the three spatio-temporal modes (Appendix D). The core modes identified were comparison, region, transition, analogy, pattern, and association. The spatio-temporal modes (space over time)
included in the syllabus were change and movement. The spatio-temporal modes of thinking emerged in the context of the spatial walks.

3. What changes occurred in spatial thinking and application of Geography 1900 students as the result of enrolling in and completing a conceptually-based inquiry course that has embedded clearly identifiable spatial tasks according to Gersmehl’s (2008) classification?

The Spatial Thinking Test was the objective measure of change. The Spatial Thinking Test was validated by Lee (2005) in prior research. The test was also used in a prior pilot study by the researcher. The Spatial Thinking Test scores suggested that students are applying increased modes of spatial thinking on the post test. The mean scores for the experimental group (N = 104) were 57.9 and 63.9 on the pre-test and post-test, respectively. The difference between the pre and post spatial thinking test scores was statistically significant at less than the .05 level (<.05). The observations were the qualitative measures of change. The qualitative measures of change were based on the classroom observations and spatial walk. The two observations were: 1) students in classroom observations used spatial thinking with regularity as reflected in their discussions; and 2) students in the spatial walk used spatial modes and concepts as they responded to and reflected on interview questions.

4. What modes of spatial thinking (Gersmehl, 2008) were Geography 1900 students applying on the post-test at the completion of the course?
The average improvement in scores from pre to post-tests suggests that students were applying spatial thinking modes (Gersmehl, 2008) at a greater frequency upon completion of the Geography 1900 course. The change in scores was statistically significant in a positive direction. There was a slight difference between the Fall Semester 2009 and Spring Semester 2009 classes. When the two groups of Geography 1900 students that exhibited no statistically significant differences in pre score were combined, the changes on the pre to post scores in the spatial thinking test were significant, using a Paired Samples t-test (Campbell & Stanley, 1963). Modes of spatial thinking also emerged in the outdoor spatial walk for most students. The data from the pre and post-tests support the following conclusions: 1) Students demonstrated an increased usage and comprehension of the modes of spatial thinking at the conclusion of Geography 1900; and 2) Students demonstrated an improved ability to address problems on the spatial thinking post-test that they did not address on the pre-test.

1. **What modes of spatial thinking do students apply outside the classroom as they move about campus?**

A subsample of twenty seven students from Geography 1900 volunteered to participate in a spatial walk and interview. The analyzed transcripts from the interviews clearly revealed spatial thinking applications. Five of the six modes: comparison, pattern, analog, transition and change were identified. Two modes, hierarchy and aura (Gersmehl, 2008) were not applied. They were hierarchy and aura. The students demonstrated spatial thinking using Gersmehl's modes in an outdoor setting as the result of the course activities. These conclusions were reached by analyzing the transcript data from the
spatial walks (examples in Appendix B). This was particularly beneficial based on the data from the spatial walks since the seven syllabus activities presented to Geography 1900 students included topographic map reading, earth-sun relationship, length of daylight, Coriolis force, isotherms and isobars, lake effect precipitation, and meteorology.

2. *Were there differences in spatial thinking between the experimental sample that experiences Geography 1900 sample of students and the comparison group at the conclusion of the respective courses?*

The Geography 1900 inquiry course was equally effective at developing spatial skills with the Spring Semester 2009 group as was the comparison Geography 1020 course. There were no statistically significant differences between the mean scores of the Geography 1900 and Geography 1020 students on the post-test, as verified using a One-way Analysis of Variance (ANOVA). These two groups experienced a different syllabus and different teaching methodologies as inquiry-based in Geography 1900 and Geography 1020 traditional discussion pedagogy. Although Geography 1900 and Geography 1020 used different coursepackets/textbooks, the material in both courses did address spatial modes. Future research suggestion would be the use of a biology, chemistry, physics, or mathematics course as a comparison group. The questions would include: 1) Do courses in other subjects include modes of spatial thinking that the students assimilate? 2) How universal are spatial thinking modes across disciplinary lines? 3) Do particular treatments in the courses result in differential results regarding spatial thinking?
Limitations

Limitations, as with any study, occurred in the research. First, all students participating from Geography 1900 were taught by one instructor. This group is represented by five combined classes for Fall Semester 2008 and Spring Semester 2009. This is a limitation, since there was no comparison instructor to determine effects of the instruction. The data from the Geography 1900 course at KVCC course was combined with the Geography 1900 students at WMU for Fall Semester 2008. Both KVCC and WMU students used the same syllabus and inquiry-based methods. However, in class observations and students interviews were not possible at KVCC. This limited the use of the sample beyond the administration of the pre and post-tests of spatial thinking. The KVCC experimental group’s outcome on the pre to post-test demonstrated statistically significant improvements in performance on the Spatial Thinking Test. This improvement supports the emphasis on spatial thinking in the Geography 1900 syllabus activities. The Geography 1020 course was also taught by one instructor. This provided stability of the content but did not permit analyzing the effects of the instructor.

Second, as a quasi-experimental design, the study did not randomly assign students and place them into the groups. The sampling was one of convenience using the available students who were enrolled in courses. A true experimental design would randomly assign students to specific groups. The specific description for sampling is a quasi-experimental design for non-equivalent groups.

Third, Geography 1900 and Geography 1020 both involve map use and analysis. Viewing physical maps in Geography 1900 is common, while regional maps integrating
spatial information about population and economics is more common in Geography 1020. Geography 1020 students completed a semester long map and atlas interpretation project. In order to make a strong comparison between science courses with very different content, an additional course may have been investigated using spatial test of spatial thinking in another context, such as a biology or mathematics course. The role of spatial thinking in all science disciplines was outlined in the literature review, and could be validated by the inclusion of other courses. In the future, courses in biology, chemistry, and physics may serve as a platform for additional research on spatial thinking and applications.

Fourth, the number of students participating in the spatial walk from Geography 1900 was twenty seven. The number of students participating in the spatial walk from Geography 1020 was eight. A sample number from each course that was comparable would enhance the reliability of the data and the analysis.

Finally, the inter-rater reliability for the analysis of spatial walk data was not feasible due to the training and funding of assistance. The deconstruction of the transcripts and the identification of the modes of spatial thinking were completed by the researcher. The protocol design for interpretation was followed for each transcript.
CHAPTER VI

CONCLUSIONS

The modes of spatial thinking were clearly embedded in the Geography 1900 syllabus and materials. These core modes of spatial thinking (Gersmehl, 2008) represented in the course were comparison, region, transition, analogy, pattern, and association. The two spatio-temporal modes were change and movement. The analysis and alignment of the syllabus and the modes of spatial thinking verified that the six core modes and two temporal spatio-temporal modes were present in seven syllabus activities (Appendix M). Hierarchy and aura were spatial modes not observed in the seven syllabus activities according to the content modes of spatial thinking analysis. Modes of spatial thinking were applied outside the classroom as indicated in field-based interviews. The analysis of the pre-test to post-test scores on the spatial thinking test suggested that students were improving their ability to think spatially as the result of the Geography 1900 course. The experimental group improved scores on the spatial thinking test from the pre to post-tests. The spatial tasks on both the pre and post-tests were identical. The sequence of tasks was altered on the post-test.

The spatial walks engaged students with their surroundings in order to detect the application of spatial thinking outside the classroom. The modes of spatial thinking were applied in the conversations between the students and researcher. The researcher analyzed the interviews for conceptual applications of the modes of spatial thinking and
not the use of specific vocabulary (modes) used to classify modes of spatial thinking (Gersmehl, 2008).

The analysis of changes from pre to post scores on the test of spatial thinking revealed that no significant differences existed between experimental and comparison groups. Analysis of pre-tests verified that students entering the experimental and comparison courses had similar background knowledge in their predispositions to think spatially. The differences (post-test minus pre-test) scores were not statistically significant between the Geography 1900 experimental, Geography 1020 comparison, and KVCC experimental groups.

The experimental groups, Geography 1900 and KVCC, received instruction from the same course syllabus. Differences were notable between the earth science/geography syllabus course content of the experimental group and the comparison group. No significant differences were observed between the groups on pre-tests and post-tests between the groups. The most notable difference between the two courses was that Geography 1020 was a world regional geography class which used a world atlas in great detail. The world geography course was not a laboratory course similar to the laboratory structure of Geography 1900 and the KVCC course. The Geography 1020 course was not inquiry-based in its design.

The qualitative observational data came from the in-class video taping and spatial walks. The researcher and co-observers wrote notes during the in-class direction observations and viewing of video; following the direct observations and video, the researcher and co-observers collaborated and the mean rating was determined from all
ratings of observers. The Pearson product-moment correlation coefficient for the activities that were co-observed indicated by SPSS (2003) analysis was .78.

The videotaping accomplished three aspects related to the Geography 1900 course. 1) Videotaping captured the interaction of the teacher and students necessary to analyze the prominence of spatial thinking tasks. Each was treated equally as reflected by the syllabus. 2) Videotaping captured the interaction between the students' conversation. Spatial thinking predispositions and responses to syllabus content were recorded. 3) Videotaping captured the interaction between the students and the materials and computer displays that represented that delivery of spatially oriented content in the syllabus.

The second set of qualitative observations was the spatial walk. All of the walks began at Wood Hall on campus and ended at Goldsworth Valley. Conversational interviews were completed during the walks. The spatial modes (Gersmehl, 2008) that were reflected by the Geography 1900 students in transcripts of the spatial walks (example in Appendix B) are presented in Figures 2-4, 7. The Geography 1900 students on the spatial walk referred to their laboratory experience during the spatial walk.

During the spatial walk, the Geography 1900 students make associations with other locations. As an example, students referred to their apartment, home city, transportation routes, or campus landmarks with the direction in which they are walking which was interpreted as spatial comparison, analogy, and association in the deconstruction of the interview dialogue. Students recalled class activities and related the Geography 1900 laboratory inquiry with the current weather. The most elaborate responses generally occurred when the outdoor weather was favorable; brief responses
were more common in severe cold weather. The study and observations of weather systems is an important part of Geography 1900 and includes modes of spatial thinking (Appendix F). The association suggests that the activities and experiments students are performing in the inquiry-based laboratory class were being applied to everyday experiences and observations outside the classroom. Students also expressed the orientation and movement of low pressure, and the location of Lake Michigan with the wind patterns, temperatures, and lake-effect snowfall using spatial concepts.

In summary, the research completed in this dissertation provided evidence for the following conclusions. Qualitative based results:

Qualitative based results: 1) Students use spatial thinking in the experimental group during the Geography 1900 activities. 2) The inquiry-based earth science course contains embedded spatial thinking modes (Gersmehl, 2008). 3) Students use modes of spatial thinking in an outdoor setting.

Quantitative based results: 1) The experimental group, Geography 1900, and comparison group, Geography 1020, both demonstrated statistically significant improvements between pre and post-test scores; 2) No statistically significant difference existed between the pre-tests of the experimental and comparison groups; and 3) No statistically significant differences existed between post-test minus pre-test scores of the experimental and comparison groups.

4) An Analysis of Covariance (ANCOVA) was used to test the accumulated data in addition to ANOVA. This test was a second analysis of the pre to post test scores. The purpose of the ANCOVA is to analyze and assess the effects of post test performance
based on pre-test scores. A significant difference was determined in the pre to post-tests scores both within and between groups when the pre-test score was used as a covariate.

Mixed methods based results: 1) The syllabus and content of Geography 1900 has a positive effect on the spatial thinking of pre-service elementary teacher education students and 2) Students who increased their score from pre to post also reflected modes of spatial thinking as they moved about campus.

Additional research is suggested for other science courses including biology, chemistry, and physics to determine change in spatial thinking of pre-service teacher education students. More sophisticated methods of spatial thinking assessment are also suggested. It is the hope of the researcher that the present and future research will lead to greater implementation of spatial thinking in undergraduate science curricula.
REFERENCES


Appendix A

Spatial Walk Interview Items:
Wood Hall to Goldsworth Valley
Interview Items:

1. Begin walking: We are beginning a walk through part of campus. Our destination is Goldsworth Valley. You may be familiar with the route. Using the knowledge of where we are presently, and the location of Goldsworth Valley, which we cannot see from here, describe any information that you need to consider in order to be certain that we will arrive at our destination by the end of the walk.

2. (Just before flag poles). Identify any objects in which you see that will be helpful in order to reach your destination.

3. (Very close to flag poles) At this location, please identify one prominent landmark. If answer is not flags, would you consider the flagpoles a prominent landmark? Describe the arrangement of the flag poles relative to each other.

4. (To the left, just past fork). What direction are we presently walking? Follow up: Are you relating this direction to anything else?

5. (Outlet lot to the left): How far would you estimate we have walked since the beginning? Looking at the apartments below, what is the estimated distance from this location?

6. (Further downslope, outlet lot left). Describe any changes in the route on this side of campus. Wait for answer. Do you recall any geography 1900 activities you may have applied?

7. End of route. What content from your Geography 1900 course have you applied or thought about as we walked today?

Thank you for participating.
Appendix B

Spatial Walk Transcript Examples

A. Geography 1900 Transcript Excerpts
B. Geography 1020 Transcript Excerpts
1. If I wasn't familiar with the area I would need a map. I would need to be able to orientate myself to the map, so I already know what direction I'm facing in accordance with the map. As it is, since I know the location of Goldsworth Valley is, I just need a few reference points to align myself and head in the particular direction—which happens to be pretty much north.

2. Well, I would say for one thing the flagpoles in the center of campus is definitely a pretty distinguishable landmark. Of course, you have Sangren Hall, and then of course you have Sindecuse. So, between the two buildings and the flagpoles, it kind of gives me a sense of my bearings as far as the campus layout. And therefore, a sense of direction. I wouldn't say the flagpoles are the most predominant landmark on campus, but as far as student meetings and places it seems to be centrally located so it is definitely a feature that students can identify with.

3. (Arrangement of flagpoles). Well, the flagpoles themselves form the shape of a triangle at their base as far as their actual layout. Um, the flagpoles all seem to be perpendicular to each other, er I'm sorry, parallel to each other in their height. I would assume there is a triangle at the base. Each one is roughly 60 degrees in separation from the vertices of itself to the other two flagpoles.

4. Uh, without being too specific, I would say we are headed pretty much due north, I would think or in a northerly direction. Well, my reference points are pretty much extensive and expansive as far as just how my mind know this is north. I know that W. Main runs east and west; I know Drake road runs north and south which is perpendicular to Drake. I also know that E. Michigan Avenue runs east and west which is again parallel to W. Main, perpendicular to Drake. The way it runs into campus, I can use it as a reference point of my directionality. It just carries into campus, so I have a pretty good idea which direction it is not to mention, you know, if you're ever out on a sunny day and watch the sun rises east and sets in the west, you have a general idea of direction based on that as well. Today, not much of a reference point with the sun (cloudy), but you have to go with it.

5. I would say probably 250 yards. All the way down to the apartments? I would say another 250 yards. About half way, I would say. Being up higher is kind of illusive as far as distance because objects look spatially different, I mean what if you're on flat ground...
6. Well, I would notice it more on the way back, but obviously the elevation is changing. We went a little bit of an incline after we crossed the flagpoles – the area just to the west of Sangren. And now, we are obviously going downhill. And, we'll notice it when we go back up the hill. There are a lot of things we talked about in terms change in elevation as far as adiabatic rates, you know, dew points and condensation points. And obviously the effect that cold air descends into lower areas and land masses. You know, they kind of hold snow longer because of the cold air. That seems to be the case down here. We have more snow down here than we had up top. Obviously, the change in altitude played a role in lots of different aspects as far as our earth science class goes. As far as elevation, we had to do the contour maps, you know, analyzing the relief and the space in between the contour lines...the gradient...The gradient you can use that to factor in the gradient, but I was trying to think of the other term of that...

7. We talked about all different kinds of things as far as, you know, precipitation and the fact that lower pressure systems seem to be more volatile and have an increase in chance in precipitation because as the warmer air is rising, it carries the moisture up to altitude which is obviously going the reach the dew point, the condensation point, and come back down. You know, there is so many different things about that and as far as lake effect snowfall, you know obviously this wasn't snow we received today but if you watched the weather report it wasn't lake effect. It was probably enhanced slightly by lake effect, but the majority of it was just from the fact that we had a cold front from the north and we had a warm front from the south that came together and collided and provided that cold air mass as all the moisture which is why we got dumped on with 6 inches of snow today. Yeah, as far as the continental polar air mass coming out of the north and you have the maritime tropical masses – they tend to be warmer coming out of the Gulf of Mexico and combine right here in the Great Lakes region and obviously in the plain states as well. Anywhere, mid-continental is where that occurs...

1. Um, I think a general sense of left and right. A lot of people, this being my first year on campus, will point me to different places by saying you need to go up to this building in front of us and take a left, and then you're going to go up to that building and turn right. That's pretty much all I needed, so far this semester.

2. Probably flagpoles, the focal point on campus.
3. Uh, they're kind of set up in a triangle shape. Uh, they're probably about six feet from each other.

4. What direction are we currently heading? I'm going to say east, but I honestly don't know. I'm trying to remember the way Westnedge runs, because I know Westnedge is behind us pretty much north Westnedge is down that way and south is down the other way, so that would make us this way. But, I'm not actually sure if that's right.

5. Probably like a quarter of a mile. I'm going to say that's a quarter of a mile as well (to apartments).

6. Like how we changed or are directions? Well, we've gone down a hill. It wasn't a very steep hill, but elevation went lower. It seems like we've generally gone in the same general direction. We've veered off a little to the left, but other than that we haven't really changed directions much. Um, there are a couple, do you want just one? (Kevin replies could be multiple). Well, I remember the one we had where we had the, uh what is that map called – the map with the different elevations on it – you can tell how high and how steep the elevations were, and the other ones were the elevations with the temperature. Yeah, it was the first few days of class. Oh, the laminated maps she passed out at the beginning of class – now I remember.

7. Um, if I were to think about it, which I wasn't...um, I could probably think about the cloud cover that I could apply with the – it shows you the cloud cover in the middle and temperature and the dew point and the air pressure – it's a little weather graph (station model), and I'm thinking of that, and I'm thinking of relating the temperature to the dew point; like right now if I would relate I would find what the chance of rain would be.

1. Um, you might need a map of campus to know where general locations of where things are. Maybe, a compass because you need to know directions like north south, and you may not know the direction you're facing.

2. Um, we are going to Goldsworth Valley, there's a pond and you go past Sindicuse. There are buildings up here, so you know you're heading in the right direction. Yes (flagpoles are prominent part of campus).

3. Well, there's like a center circle in the middle and then the flagpoles are located on the outside. Um, they're all symmetrical with the steps up and being in the
middle with three flagpoles in each separate location. Mostly spaced the same distance. It's like two of them may be taller than another one. They're general shape is the same.

4. Um, north, northwestish. Because I know relative to the campus, that this would be the north end of campus and that – behind us would be the south end of campus.

5. Um, I'd say a quarter of a mile at most. Um (to the apartments) 300 meters.

6. Well, there's a lot less people. It's surrounded by a lot more grassy landscape. Yes, now we're at a lower elevation. Um, yes we used the topographic maps to like determine elevation. Um, that's the only one I can think of right now.

7. Um, clouds. The weather part, I could tell it's raining consistently kind of, and so I predict it will continue to rain at a consistent rate based on the way things are today. Um, we talked about precipitation in terms of the climate type and so we receive rainfall here much more here than they would in a desert. Um, we talked about the cloud cover, and today would definitely be 100% cloud cover and the rain is part of that. It's raining because the clouds are full of rain and water droplets. They had to release the water droplets because they're too heavy.

1. Um, like a map on campus to see where the sidewalks head towards or the road, because you can take a car to Goldsworth Valley.

2. The flagpoles (most prominent).

3. Um, in a triangle in a cement circle. They're silver and they're the same height.

4. Um, south. I think of the highway, I'm not sure if it's right. 94, because it's going to the right, so maybe that's me going north. So maybe we're going south or west.

5. Um, less than a fourth of a mile. (to the apartments) a fourth of a mile, too.

6. Um, the elevation changed and you could go a different way I think. You could take the left route, because this is where the sidewalk says. Um, we connected like lapse rate with mountains. I know on the mountain thing, we did the windward and leeward side.
7. I think like the temperature and mostly everything except air pressure, because I don't really understand what that is still. Temperature and precipitation. I understand more like the latitudes affects temperature.

B. Geography 1020 Students

1. A map. I know online there are little maps on campus. Or a friend.

2. Maybe the map right there (WMU map, prominent landmark). Or like this here actually (circle). Whenever I can't find myself, I'm like where are the flagpoles and then I got to figure out from there where the building is. And this is pretty much in the middle of it.

3. Same height, equal distant from each other. They're pretty much all the same.

4. Honestly, I'm not sure. We're walking down hill...south just to guess. Well, I wish I could figure out which way we are going. I'm the worst person to figure out which way is north, south, east, and west. People give me directions, and I say don't say that. Tell me to turn right or left. Don't give me north, south, east, or west. I used to have a car that had the little thing that would tell me direction.

5. Maybe a quarter of a mile. (to the apartments) I'd say like 500 feet.

6. Hill. Downhill. And I think the sidewalk is wider. Yes, we had to look at the mountains. We had to figure out how far (on study guide), and which is on the higher elevation. Each map for the country we used.

7. It taught me how to read a map better. Just to become more familiar with the world. Reading maps and being more familiar.

1. Direction (student laughs). Like reference points, different buildings and the pathways available to take.

2. Ok. To the right there's the flagpoles and on the left the honor's college and one in between them. Yeah (flagpoles are important), I feel like it's central of everything.

3. Um, there's three sets of flagpoles with a circle in the middle. Each set of
flagpoles has three flags. Um, they're in a triangle on top of a circular platform.

4. We're walking towards the Goldsworth Valley. (student laughs). I really don't know. I'm really bad at that. If I had to guess...um...north. I was kind of thinking about the expressway (student laughs). Um, 131. Yeah (replies to follow-up question - says she associates with streets). The sun and sun directions.

5. Um, 200 yards (student laughs). Um, I would say about 150 yards (student laughs).

6. We've been walking downhill most of the way. Um, been on this straight path. Yeah, we talked about mountains and other locations (physical maps). Every continent.

7. Um, change in elevation. I don't know...do you have an example, like? Um, well, the weather I guess. It's getting warmer than it has been. Yeah (long term). I guess the culture aspect. You can just look around campus and see all kinds of people.

1. Probably a map, or at least instructions from a building that I'm familiar with. Most likely a map.

2. Uh, Sangren Hall. Yeah, (flagpoles) it's easy to explain where something is.


4. East. I try to think of the building I live in – it's only three miles away. It would be exactly where we are walking.

5. Two and half football fields. 250 yards. 175 yards (to the apartments).

6. There's not as many buildings. Yeah, it's downhill. (relates to) a map showing elevation with physical features.

7. Figuring out where to get to places.
Appendix C

HSIRB Approval Letter

*Previous Working Title: Factors and Instructional Effects on Spatial Thinking for Preservice Elementary Teacher Education Students
Date: April 13, 2007

To: Joseph Stoltman, Principal Investigator
   Kevin Weakley, Student Investigator

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number: 07-04-01

This letter will serve as confirmation that your research project entitled "A Task in Spatial Ability" has been approved under the expedited category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: April 13, 2008
Appendix D

Initial Matrix of Spatial Modes of Thinking Embedded in Geography 1900 Activities
Analysis of Spatial Modes Embedded in the Seven Syllabus Activities  
(X=Embedded Mode)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comparison</th>
<th>Region</th>
<th>Transition</th>
<th>Analogy</th>
<th>Pattern</th>
<th>Association</th>
<th>Change</th>
<th>Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Topographic Maps</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>2. Length of Daylight</td>
<td>X</td>
<td>X</td>
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<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3. Sun Angle</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>4. Mapping I</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>5. Winds II</td>
<td>X</td>
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<td>X</td>
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<td>6. Mapping II</td>
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<td>7. Lake Effect</td>
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<td></td>
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Appendix E

Observation Protocol
Observation Protocol for Geography 1900

Spatial Activity

Video Observation of Length of Day activity (January 26, 2009): August 14, 2009

This activity may exhibit the following modes of spatial thinking which students utilize during their problem solving. The following is a ranking system from 0 (low) to 7 (high) to assess the degree of which these cognitive skills are identified through conversations and discussions within groups and as a class during the inquiry activity.

Spatial Thinking:

1. Comparison – How are places similar or different? How can we compare them?
   Low 0 1 2 3 4 5 6 7 High

2. Region – What nearby places are similar to each other and can be grouped together?
   Low 0 1 2 3 4 5 6 7 High

3. Transition – Is the change between places abrupt, gradual, or irregular?
   Low 0 1 2 3 4 5 6 7 High

4. Analogy – What distant places have similar situations and therefore may have similar conditions?
   Low 0 1 2 3 4 5 6 7 High

5. Pattern – Are there clusters, strings, rings, waves, other non-random arrangements of features?
   Low 0 1 2 3 4 5 6 7 High

6. Association (Correlation) – Do features tend to occur together (similar spatial patterns)?
   Low 0 1 2 3 4 5 6 7 High

Spatio-temporal:

7. Change (in conditions at a place over time)
   Low 0 1 2 3 4 5 6 7 High
8. Movement (of something over time)
Low 0 1 2 3 4 5 6 7 High

The level of instructional inquiry (observations, experimentation, questions):
Low 0 1 2 3 4 5 6 7 High
Appendix F

Geography 1900 Syllabus Activity Descriptions
TOPOGRAPHIC MAPS

Concept: The most useful maps for studying landforms are topographic maps. Topographic maps are a two-dimensional surface which represents the three-dimensional earth. In order to show topographic features - hills, valleys, mountains, cliffs - these maps must depict elevation. To do this, cartographers use **contour lines** to show how elevation varies within the area covered. Contour lines are generally depicted in brown, connecting points are equal elevation above sea level. The **contour interval** will tell you how much distance is between each brown line. Every fifth line is an **index contour**, which is usually a darker brown line with the elevation written along the line.

Objective: To read and understand topographic maps.

Note: Rules for topographic maps:
- a. all points on a contour line are the same elevation above sea level.
- b. contour lines are never split or cross.
- c. contour lines close together represent steeper slopes than widely spaced contours.
- d. contours with hachures indicate depressions

Activity Part 1 – Reading Topographic Maps

Materials:
Topographic map

Procedure:
Answer the following questions based on the contour map below. Elevations shown are in feet. North is to the top of the map. Streams are shown with dashed lines

Outcomes Part 1:
1. What is the contour interval?

2. What is the approximate elevation of Point A?

3. What is the approximate elevation of Point B?

4. What is the approximate elevation of Point C?

5. Which lettered point has the highest elevation?

6. Which lettered point has the lowest elevation?

7. What is the elevation of the highest location?

8. What is the elevation of the lowest location?

9. What is the “local relief” (difference in elevation between the highest and lowest locations) of this landscape?
10. Is it possible to see D from F?

11. Is it possible to see D from B?

12. Draw a circle around the location with the steepest slope.

**Activity Part 2 – Interpreting Topographic Maps**

**Materials:**
Schoolcraft NW Topographic quadrangle

**Procedure:**
Use the Schoolcraft NW Quadrangle topographic map to answer the following questions.

**Outcomes Part 2:**
1. According to the scale on the map, how many feet on the ground are represented by one inch on the map? One mile (5280 feet) is equal to how many inches on the map?

2. What is the contour interval of this map?

3. What is the highest elevation on the map? What is the lowest elevation on the map? What is the total relief of the map area?

4. The distance between Pretty Lake and Limekiln Lake is approximately 16 inches on the map. What would be the gradient between Pretty and Limekiln Lakes?

5. Because water flows from higher to lower elevations, what can be said about the flow through this chain (Pretty - Limekiln) lakes?

6. How do you think these lakes formed? (Hint: Crooked Lake, Bass Lake, and Atwater Mill pond mark the outer border of the outer Kalamazoo moraine, a glacial feature).

7. Based on the map alone, if you had no other knowledge of this area, what kind of topography would be found in the northwest part of this map? Why? What type of topography would be found in the south-southwest part of this map? Why?

**ENERGY INPUT II: LENGTH OF DAYLIGHT**

**Concept:** Previously you investigated how global surface temperatures vary latitudinally and seasonally. What are the reasons for these variations? One possible explanation could be the time the earth’s surface is exposed to the sun's radiation. In this activity you may use a computer simulation to investigate the latitudinal and seasonal variations in length of daylight and test your hypothesis.
Before you begin:

1. The earth's axis is tilted at 23.5° from the perpendicular to its plane of orbit around the sun. (Make a sketch of this.)

2. The earth rotates on its axis once every 24 hours, so that any point on the earth's surface passes into and out of the sun's illumination once every 24 hours creating day and night. (Sketch this as well.)

3. How does the length of daylight vary latitudinally and seasonally?

4. Does length of daylight affect global surface temperatures?

5. Develop a hypothesis on the relationship between the length of time the earth’s surface is exposed to the sun’s radiation and the surface temperature. What data will you need to test the hypothesis?

Activity:

Materials:
Website (listed below) and computer
Length of daylight maps

Procedure:
The WWW site in this activity allows you to study the patterns of daylight latitudinally and seasonally.

1. WWW site: [http://www.fourmilab.ch/earthview/vplanet.html](http://www.fourmilab.ch/earthview/vplanet.html). From the home page of the WWW site select: map of the earth

2. Select Display: Map. Leave latitude, longitude, and latitude at its default setting. Image: Living Earth. Time: UTC 2008/03/21 12.00.00. UTC is Universal Time at the prime meridian (0º). The prime meridian passes through Great Britain. Therefore, you have selected noon in London on 21 March 2007. What is the significance of this date?

3. Click: Update.
The map shows the areas of the globe that are in daylight at noon UTC on 21 March. Study this map carefully. What is the latitudinal variation in length of daylight at this time of year for the earth?

4. To access another simulation change the time or date or both and click: Update. Make a number of observations at various latitudes using different dates and times of the year.

5. Ascertain in which direction the earth rotates. Draw an arrow to show the direction of the earth’s rotation. Explain how you determined this.
6. Analyze the latitudinal variation in daylight length throughout the year. Identify the four most significant months of the year with respect to length of daylight. Use the handout to depict the four most significant months with respect to length of daylight. Clearly label each map with the date and time of the observation.

Outcomes:
1. Write general statements to describe how length of daylight varies latitudinally and seasonally.

2. Describe how length of daylight varies seasonally at:
   a. the equator
   b. north and south poles

3. State your hypothesis on the relationship between the length of time the earth’s surface is exposed to the sun’s radiation and the surface temperature. Do you think the latitudinal surface temperatures fluctuations you discovered in a previous activity result from the changes in the length of daylight? Explain in detail the differences and similarities in length of daylight and surface temperature patterns. Do your observations confirm or contradict your hypothesis? Think carefully about this question.

4. Speculate on other factors that may be influencing surface temperatures, apart from length of daylight.

Reflections:
Explore the website earthview a little further (http://www.fourmilab.ch/earthview/vplanet.html). Look for a presentation illustrating the “circle of illumination.” (IT WILL NOT BE LABELED) Sketch what you believe illustrates this and then develop a definition for this term.
Length of Daylight Maps
ENRERGY INPUT III: SUN ANGLE

Concept: As you observed from the computer simulation in the previous activity, the Earth’s axis is tilted by 23.5° from the perpendicular to its plane of orbit around the sun. This tilt combined with the spherical shape of the Earth results in the sun’s rays striking the surface at different angles. This sun angle could be another possible explanation for the latitudinal variation in global surface temperatures. In this activity you will investigate the effect the changing sun angle on the heating of the earth's surface.

Before you begin:
1. What is the effect of the angle of the sun’s rays on surface heating?

2. What is the effect of the earth's orbit on surface heating?

Activity:

Materials:
Inflatable globe  Flashlight

Procedure:
1a. Shine a light at various angles on the dark tabletops or a dark piece of paper. Describe the various shapes created by the light. What else changes as you change the angle? Could you measure the angle, if so take three, four, or more different measurements.

1b. Repeat what was previously done, but instead of using the tabletops use the inflated globe.

1c. Make sketches illustrating the energy from the sun as it hits the earth. Base your sketches on the information you gathered from your observations.

1d. From your sketch can you describe when the sun angle is the greatest and when it is the least. Where is the sun’s energy most intense? What relationship is there between sun angle and intensity of the energy? What area would have the greatest heating?

Earlier you conducted an activity observing the seasonal variation in surface temperature. What causes this seasonal change? An investigation to answer this question is based on the elliptical orbit of the earth. The earth revolves around the sun once every year.

2a. Use an inflated globe and a flashlight to model how the orbit of the earth produces the seasons. Draw a model and explain the relationship between the earth's orbit and the seasons.
2b. Explain the latitudinal and seasonal patterns of surface temperatures for the first day of Spring, Summer, Fall, and Winter.

**Reflections:**
Open WorldWatcher, Energy Balance and choose Incoming Solar Energy. Using the most significant months of the year, view the maps and make comparisons in order to answer the following questions.

1a. At what latitudes do the highest and lowest values occur? Why?

1b. Which hemisphere receives more energy from the sun during the month of January? How can you explain this?

1c. Compare your observations to your surface temperature data and come up with a summary.

2a. Describe how the earth’s *rotation* and *revolution* affect life on earth.

2b. Explain why solstices and equinoxes have historically been so important to cultures all over the world.
MAPPING METEOROLOGICAL DATA I

Concept: Weather stations located across the earth's surface and meteorological satellites constantly record atmospheric data. Before these data can be analyzed and interpreted, the information is first mapped. In this activity will you will map temperature and pressure data for the United States using isolines. An isoline is a line on a map which joins points of equal value, such as locations with the same temperature or pressure.

Before you begin:
How can temperature and pressure data be shown spatially?

Activity:

Materials:
Surface air temperature map
Surface air pressure map

Procedure:
Isolines joining points of equal temperature are called isotherms.

1a. Carefully study the distribution of temperature data points shown on the surface air temperature map. Look for regions of similar temperature values. Find the lowest and highest values. Determine the range of temperatures shown.

1b. Choose a suitable isotherm interval.

1c. Draw smoothly curving isotherms between points of equal temperature. Some of these you will have to interpolate (estimate).

Isolines joining points of equal pressure are called isobars.

2a. Carefully study the distribution of pressure data points shown on the surface air pressure map. Look for regions of similar pressure values. Find the lowest and highest values. Determine the range of pressure shown.

2b. Choose a suitable isobar interval.

2c. Draw smoothly curving isobars between points of equal pressure. Some of these you will have to interpolate.
Outcomes:

1. Describe the distribution of temperature over the USA – where is it warmest and coldest?

2. Explain this pattern in terms of latitude, sun angle (intensity), and hours of daylight.

3. Describe the distribution of pressure over the USA – where is the highest pressure and where is it the lowest?

4. Explain the pressure pattern in terms of air density and motion – is the air more or less dense and is the air rising or falling?

5. During what time of year do you think these data for temperature and pressure were recorded? Explain why.
ATMOSPHERIC MOTION: WINDS II

Concept: Consider the unicellular world model of wind flow. In that model the prevailing wind direction in Michigan was northerly. In this activity you will investigate how the rotation of the earth affects wind flow and direction.

Before you begin:
How and why does the rotation of the earth affect wind flow and direction?

Activity:

Materials:
Paper plate
Tape
Marker
Coriolis Effect (Handout 1)

Procedure:
1. What is the effect of the movement of a spinning disk on a line drawn along a straight edge held above the surface? Use the materials provided to investigate what happens.

2. Experiment with different line lengths and directions and locations. Make sure that you spin the turntable in the direction of the earth's rotation.

3. Describe the effect of the spinning turntable on your "straight" lines. Are some lines deflected more than others? In which direction are the lines deflected? (Imagine you are standing looking in the direction in which the line was drawn when you determine the direction of the deflection.)

4. The deflection of the line is called the Coriolis Effect. Where is this effect strongest and where is it weakest?

Outcomes:
1. Draw a diagram to show how the two forces, pressure gradient and Coriolis effect, influence wind flow. Label the diagram "Upper-Air Wind Flow."

2. When the wind blows near the earth's surface another force affects wind flow, what is this force? In which direction will this force operate? What effect will this force have on the wind?
3. Draw another diagram to show how the three forces affect wind flow in the lower atmosphere. Label this diagram "Surface Wind Flow."

4. Redraw your unicellular model of global wind patterns. Add the surface wind directions that result from the Coriolis effect. Remember the direction of the deflection caused by the Coriolis effect is reversed in the southern hemisphere. What is the general wind direction in the Northern Hemisphere? Is this the prevailing wind direction in Michigan?

5. Attempt to construct a model that explains the prevailing wind direction for Michigan. Remember you must maintain the circular nature of air flow within the atmosphere and the concepts you have learned about wind generation and deflection. The pressure patterns at the equator and poles must also remain the same.

Reflections:
Since air does not flow directly from high to low pressure because of the Coriolis effect, the winds tend to spiral out of high pressure centers and into low pressure centers. Apply the concepts you have learned in this activity to determine the pattern of wind flow around a center of high pressure and around a center of low pressure in the northern hemisphere. Illustrate your answer on Handout 1. Make a generalized statement about each. Repeat for the southern hemisphere.
HANDOUT 1

Northern Hemisphere

Southern Hemisphere
MAPPING METEOROLOGICAL DATA II

Concept: In this activity you will interpret annual precipitation data for the World. The data are shown using isohyets.

Before you begin:
1. How can world annual precipitation data patterns be described and interpreted?
2. What is the Intertropical Convergence Zone ITCZ)?

Activity:

Materials:
Website and computer

Procedure:
This activity is a mapping exercise, which requires you to apply all the concepts that you have learned in previous activities to explain the isohyet patterns.

Outcomes:
1. Carefully mark on your map the:
   a. ITCZ (Intertropical Convergence Zone)
   b. Polar and Subtropical Highs
   c. Equatorial Low, and Subpolar Low
   d. The global winds in the appropriate latitudes

2. Describe the distribution of world precipitation within these regions:
   a. Equatorial regions (between 10°N and 10°S).
   b. Tropical regions (between 10° and 30° N & S).
   c. Temperate regions (between 30° and 60° N & S).
   d. Polar regions (between 60°N & S and the poles).

Reflections:
1. Look for regional precipitation patterns. Can you make a summary statement explaining a relationship between certain latitudinal areas of precipitation and world wind patterns?

2. Is there a relationship between amounts of precipitation and elevation? Does the data support your hypothesis?

3. How about a relationship between precipitation and distance from bodies of water?

4. How does the seasonal shift in surface temperatures affect global pressure, wind belts, and precipitation patterns.
LOCAL WEATHER PHENOMENA II: LAKE EFFECT

Concept: Proximity to large inland water bodies can have a profound effect on the weather. In this activity you will determine how the Great Lakes affect snowfall and agriculture in the region.

Objective: To determine the cause of lake effect snow in the Great Lakes, explain the distribution of the snow belt and the distribution of fruit crops in the Great Lakes region.

Activity:

Materials:
Map: Average annual snowfall in the Great Lakes region
Map: Fruit growing areas in the Great Lakes region

Procedure:
Study the maps of snowfall and fruit growing areas in order to answer the questions below.

Outcomes:
1a. What do the isolines on the snowfall map show?

1b. Identify regions that experience the highest snowfall amounts. Write a generalized statement to describe the location of these regions.

1c. Explain why these regions experience high snowfalls and why regions tend to be linear in shape.

1d. What other information do you need to fully explain the distribution of regions of greatest snowfall? How would this give you a better explanation of the distribution?

2a. Analyze the map. Write a generalized statement to describe the location of the fruit growing regions.

2b. Fruit crops are particularly sensitive to frost damage at blossom time. Explain why fruit crops can be grown on a large scale in these regions, but not elsewhere in the Midwest to the same extent.

3. Summarize the modifying influence of the Great Lakes on the weather of the region.
4. Summarize the causes and distribution of lake effect snow in the Great Lakes region. Illustrate your answer with a concept sketch.

5. Summarize the reasons for the distribution of fruit crops in the Great Lakes Region.

Reflections:

1. Reflect on the ways the proximity to Lake Michigan affect the lifestyle, economy and occupations of residents in southwest Michigan.

2. During which month(s) of the year would you expect lake effect snow to be most prevalent? Why? During which month(s) of the snow season would you expect lake effect snow to be least prevalent? Why?
Average annual snowfall in the Great Lakes region
Fruit Growing Areas in the Great Lakes Region
Appendix G

Researcher’s Geography 1900 Observation Notes

Fall Semester 2008 and Spring Semester 2009
September 8, 2008

Activity: Topographic Maps
Time: 9am class.

9am. Students are working on the topomaps. Question: “what’s the difference in elevation” asks a student. “You have to follow the lines.” “Is this north?” “Gradient – what is a gradient?” “I don’t know.” Students continue conversing in discussions. “I did this in high school, but it’s been so long – I don’t remember.” “It’s more hilly around places that have lakes – elevation changes.” “The lines represent differences in elevation.” “The glacier came from this way.” Answers are revealed in the outcome questions/discussions.

Activity: Topographic Maps
Time: 1pm class.

Student conversation: “We found northwest – I would assume more mountains, higher elevations. I’d say less mountains, lower elevation, more wetland. It really doesn’t change. South/southwest toward Chicago. Steep gradient. I would say northern higher elevation; lower less elevation, more wetland. You can tell the highest elevation decrease on the way down. There are ‘scrunched’ up lines”

Activity: Air Pressure
Time: 1pm class.

1:30pm. Question posed by instructor: “Which way is air pressure acting?” Student replies: “up.” Instructor later explains: “up – in all directions…works in all directions.”

1:45pm Discussion on the dense surface, decreases as you go up. “More pressure – is it more or less dense?” “It’s more dense, change in elevation…has to do with the wind lines.”

Activity: Length of daylight/Sun Angle
Time: 9am class.

9:45am. Instructor poses a question for the students: “How does our daylight vary in Michigan?” Student replies “less daylight in winter.” Instructor asks “When we have shorter days, what happens?” Student replies “It’s colder.”

10:00am. Students working to determine the direction the earth rotates (west to east or east to west).
10:15am. Student suggests: “As daylight gets longer, it gets warmer.” Another student: “The earth is round; there is a circle of light.”

10:30am. Student: “Warmer relative speaking at the equator.”

Students begin the modeling of the earth.
Student suggests “the more direct the sun, the warmer it is.” The elliptical orbit of the earth around the sun is shown on the whiteboard with dates of aphelion (July 4) and perihelion (January 3).

10:45am. Instructor asks: “What is changing besides the shape?” Student replies “The amount of light?” Instructor: “What else is changing?” Student replies “The direct rays.” Conversation continues with concept that 90 degrees goes along with the ‘direct rays.’ Those with less than 90 degrees are called ‘indirect rays.’ Instructor explains the revolution. Homework is assigned.

Observation: Length of daylight/Sun Angle
Time: 1pm class.

1:15pm. Class is doing sketch drawings. Instructor explains about more variance, the further you are away from the equator – equal at the equator. Instructor poses question: “Length of daylight affects surface temperatures?” “Yes.” Students continue working on the computers and visualize earth moving from west to east.

1:30pm. Explanations and discussions with the students. More daylight equals warmer temperatures. Students recognize variation depending on seasons. More daylight leads to longer exposure of sunlight at the surface.

The elliptical orbit of the earth around the sun is shown on the whiteboard with aphelion (July 4) and perihelion (January 3). Instructor asks “What happens at the poles?” Student replies “They have more extremes.” The circle of illumination is explained: “half of the earth is lit up.”

Observation – Mapping 1
October 6, 2008
Time: 9am class.

9:45am. Students are drawing isolines; they are quiet and there is little conversation.

10:00am. Students are talking about similarities. “These are all like rings.” Students are looking at the areas of different locations.

10:15am. Question posed by Instructor: “Would high pressure be high or low density?”
Observation – Mapping I
October 6, 2008

1:30pm. Instructor explains that places where you don’t have temperature, you interpolate where you would put them. Conversation is quiet to light at the tables.

1:45pm. Students are looking at various cities and making comparisons – Dallas, Kansas City, and Chicago. Student says “all the rest of them are less than 50.” Students are looking at the closeness of the stations. One student says “I’m so confused.” Student shows the overhead image of the isotherms.

2:00pm. Conversation continues. Air is less dense in high elevation. “Weather changes all the time” says a student. The students notice that the map is for one particular day.

Observation: Winds II
October 13, 2008
Time: 9am class.

9:30am. Students are drawing the unicellular model on their small whiteboards. Students use the Lazy Susan turntable and spin the table while looking down on the north pole (center of paper plate). Student suggests curve away from the north pole (center of paper plate) should be ‘to the left’; another students suggests ‘should be to the right’. Students rotate the plate counter-clockwise and observe... explains about decrease of the Coriolis further away from the poles and more of an effect closest to the poles.

Instructor explains the pressure gradient force, as curving to the right in the north (hemisphere), and to the left in the south. The forces are drawn on the whiteboard and the Coriolis effect is drawn (curving to the right in the N.H.), too.

9:45am. Instructor asks students to think about air from the North Pole to the equator. A student asks “wind comes down, but how does it go back?”

Observation: Winds II

1pm. Students draw the unicellular model on their small whiteboards. Students rotate the turntable. Instructor asks the direction of curvature. Student says “left”; Instructor says “to the left.” She continues explaining that the deflection of the line of called the Coriolis Effect. “It will curve to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere.

Instructor shows the nature and direction of the pressure gradient force from high to low pressure. Instructor asks “What could we add to the whiteboard to show the Coriolis?” Student suggests that “We just showed arrows.” Instructor asks the students to identify another force that is relevant: friction.
1:30pm. Instructor poses the question: “What is our predominant wind direction in Michigan?” Students answer “Southwest.” “West.”

There is a discussion on the convection cells on earth; as a similarity. Instructor compares this with the lava lamps.

2:00pm. Reflection questions related to isobars and high and low pressures.

2:15pm. Students are quietly working on the rotations- high and low pressures.

November 10, 2008
Activity: Lake Effect
Time: 9am class.

9:30am Students are discussing and thinking about the pattern of lines (snowfall).

9:45am. The discussion reveals students are thinking about the relevance of an air mass to warm the lake.

10:00am. Students are related to the southern locations and effects on businesses. Instructor asks students to think about the wind direction required to get the lake effect snow.

10:15am. Students are discussing the locations very near to the lake. They identify this are as being good for fruit growing. The discussion as a class is related to the outcome questions as the effect of where you live and vacation. Students identify the months of November and December as most prevalent, while months of February and March less prevalent in the winter season.

November 10, 2008
Activity: Lake Effect
Time: 1pm class

1:15pm. Students are viewing the map on page 86. Questions are asked as which locations have the most snowfall and describing the shape of the lakes. Students discuss the comparison with the lake and shape of land. – Discussion then gets off topic. “Right long the lake it is a little warmer” suggests one student.

1:30pm The specifics over the land are discussed and the temperature of water, land, and possible dew point temperatures. Instructor asks students which air mass is dominant and location. Students then view the fruit growing regions. A student identified that the temperatures will be moderate and close to the lake. Students continue working on pages 87-88.

1:45pm. Students continue discussions. Discussion is off subject at times at a specific table. Instructor mentions that the class will discuss the outcome questions around 2pm.
2:00pm. The effects of tourism, fuel cost, and the economy are discussed in connection with lake effect snow and the fruit growing regions. Instructor describes that the lake effect process is prevalent when there is larger temperature differences between the lake and air. The least effect occurs in late winter.

Spring 2009 Semester

January 7, 2009
Activity: Topomaps/Composition of the atmosphere
Time: 1pm class

1:30pm. Instructor asks several questions to the students.

2:00pm. Students are engaged in discussions.

2:15pm. Instructor poses the question: “What is meteorology? The science of what?” A student replies: “the science of weather.” The layers of the atmosphere are assessed. Instructor asks for the components of weather and students suggest temperature, precipitation, pressure, etc.

January 7, 2009
Activity: Topomaps/Composition of the atmosphere
Time: 5:30pm class

6:15pm. Students continue working on the Kalamazoo laminated map.

6:30pm. Instructor reviews, discusses, and gives answers to the outcome questions on page 20.

6:45pm. Students talk about weather and it is defined. Instructor poses question: “What is meteorology?” Student replies “study of weather.” The permanent gases and variable gases are outlined, as well as particulate matter on the whiteboard by instructor.

7:00pm Students review the layers of the atmosphere.

January 26, 2009
Activity: Sun Angle/Length of Daylight

10:15am. Students view the sun angle first. There more direct sunlight, the warmer the temperatures is a central concept.

Instructor reviews revolution and rotation. Instructor asks “What is a solstice and equinox?” Equinox is day and night instructor describes. An experiment shows the student with a flashlight that the size of area is changing – spatially.
11am. June solstice is viewed on the board along with December solstice on the other side. Students draw seasons on their mini-whiteboards.

11:15am. Students view the “Earth Moon Viewer” on their computer screens.

11:30am. Students are discussing the sun angle, length of day, and latitude in order to create an association.

11:45am. Homework assignment is given to the class.

January 26, 2009
Activity: Sun Angle/Length of Daylight

1:15pm. A figure is on the board with the elliptical orbit of the earth moving around the sun. The aphelion even (Jan. 3-4) and perihelion event (Jan. 3-4) is displayed on the board. Instructor asks “What’s the difference between rotation and revolution?” The solstice represents the first day of summer and first day of winter. The equinox represents equal day and equal night.

1:30pm. Instructor asks “How do we get our seasons?” Student then shows the model earth and flashlight, with the earth tilted and moving around the sun in a revolution.

1:45pm. Class discussions continue.

2:00pm. The circle of illumination is addressed. Question posed by instructor “Are we moving east to west or west to east?” Instructor then explains “We are moving counterclockwise.”

2:15pm. Students continue to work quietly.

2:30pm. Students working and discussing. A student suggests daylight changes because we are moving....(rotation).

February 9, 2009
Mapping I (Isolines)
10:30am. Isolines pts. connecting equal values
Isotherms - temperature.
Isobars – pressure

Question by instructor: “How can we connect these?” Isolines are drawn on the board by instructor.

Instructor explains even further. The students are beginning to interpret the maps. I notice certain words are being used often in association with shapes, such as ‘circles.’
11:00am. Students continue working on isotherms. There is a discussion on isotherms. Instructor then shows the students the isotherm map on the overhead.

11:15am. Students continue discussions. The students appear to be discussing direction..."farther from the..." Discussions include the location of water and the correlation between higher pressure and higher density.

11:30am
Students are finishing with their work. The class discusses the final outcome questions.

February 9, 2009
Activity: Mapping I (Isolines)

1:20pm. Review of lapse rates.

1:30pm. Interpreting isotherms and isobars defined..."we’re going to learn how to draw them."

1:45pm. Instructor continues to describe the isotherms and talking about the different values. Instructor stresses that the interpretation of the isotherms is important.

2:00pm. Students continue discussions and talking about water.

2:15pm. Students continue discussions.
February 16, 2009
Activity: Winds II

10am. Students view an animation of the sea/land breeze on the computer.

10:15am. Students have the turn tables and spin them for the Coriolis effect simulation. Instructor shows the example with the globe. Instructor asks “Did you find more tightness near the center?” Student replies “The poles.” Figure is drawn of the Coriolis effect in the northern hemisphere and southern hemisphere.

10:30am. Students are using the individual whiteboards. Discussion about direction of winds is common in the dialogue.

10:45am. On the overhead, instructor shows a transparency showing high and low pressures.

February 16, 2009
Activity: Mapping II

11am. Students are drawing the global belts on the precipitation map; discussion continues, and there is light conversation. There are questions, and a discussion about the Inter-tropical Convergence Zone.

11:15am. Students view the web page, and the animation sequence shows the ITCZ migration north and south of the equator. Students continue working on the outcome questions.

11:30am. Students are still working on the computer. Instructor is talking with students at a table. The students are asking about high winds. Conversation then continues with warmer temperatures years around hold more water. Instructor asks students for the location where there is least precipitation. “Polar region…can’t hold as much water…it’s so cold.” The rainshadow effect is explained by instructor with the windward and leeward sides of the mountain. Instructor discusses the cooler side (with rain) being the windward and the leeward side being warmer-dry and desert like. Precipitation patterns shift with the ITCZ.

11:45am. End of class.

February 16, 2009
1:00pm
Activity: Winds II
On the whiteboard, instructor shows the equatorial low and the polar highs.
1:15pm. The pressure gradient force (PGF) is outlined on the whiteboard. Then, the forces that act upon the wind, such as a friction which slows the wind is explained. These are the three that act upon wind explained by instructor: PGF, Coriolis, and Friction.

1:30pm. Discussions continue. Instructor is walking around the tables. The example of the lava lamp is stressed in the conversation. Instructor explains the direction of surface wind coming into the equator, while the upper level wind flows back to the poles.

1:45pm. The display of the tri-cellular model is on the whiteboard. The flow of circulation from the high pressure to low pressure is outlined. Rotations are explained with the high pressure rotating clockwise. “High pressure rotates clockwise or counter-clockwise?”

2:00pm. The precipitation pattern are explained.

2:15pm. Discussion on pattern. Pattern is a common word expressed in this activity.

2:30pm. The circulation of air flow over a mountain is expressed as rain on the windward side and warmer-dry conditions on the leeward side.

March 16, 2009
Observation: Lake effect snow
Time: 10am

11:15am. Students are looking at the isoline maps and working on page 84 as a class. A map of Michigan was drawn on the whiteboard by instructor. Instructor asks “How many miles away from water do we have the greatest number (snowfall inches)?” Answers “10-15 miles away from the water.” That small chunk will have the greatest snowfall.

Instructor asks “What are the causes (of Lake Effect Snow?)” Student replies: “More moisture in the air.”

11:30am. Students are looking at the fruit growing region map on page 87. Question: “Where are the fruit growing regions?” Why: “Water moderates the temperature. Think of the Fall. What are temperatures like?” Student replies: “Warm. In the Fall and early winter, there are warmer winds from the lake.”

11:45am. Students are looking at the northern shores vs. the southern shores (comparison). Students are looking at direction; Gary is opposite of Chicago. Students then work on review questions.

12:00pm. Instructor reviews and asks for other factors that influence lake effect snow: Students reply: “time of the year; less snow later in the season, and more earlier in the winter.”
March 16, 2009
Time: 1pm class
Observation: Lake effect snow

Activity starts at 2pm.

2pm. Instructor asks the question: “What do isolines show us?” No answer from students. Instructor quickly replies “shows us average annual snowfall in inches. Students discuss direction and locations south and east of lakes. Within 20-25 miles, we have the greatest amount of snowfall.

2:15pm. There is a discussion on the moderation of locations near water.

2:30pm. The class is discussing the remaining questions on page 88: “Moderate temperatures” continues to be raised in discussion dialogue.

2:45pm. Students are discussing the outcome questions.
Appendix H

Observational Questions on Video: Sun Angle Example
Observation Notes of Video (January 26, 2009): August 4, 2009

1. What are some of the questions asked by the instructor to the students?

2. What are some of the questions or responses from the students to the instructor?

3. What do you observe students doing in this activity? Which part of the activity do you believe is most closely related to thinking spatially?

4. List the three most prevalent modes of spatial thinking being exemplified in the group work and discussions:
Appendix I

Geography 1900 Spatial Walk Invitation Sheet
My name is Kevin Weakley, and I am a Ph.D. Candidate in the Mallinson Institute for Science Education. I would like to invite you to participate in my dissertation research by going on a campus walk-through spatial task (15 minutes). You will receive extra credit for your participation. Please sign below with your email if you are interested, and I will contact you. Thank you.

Name: ___________________________ Email: ___________________________

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20. _____________________________________
Appendix J

Fall Semester 2008:
Geography 1900 (9a.m.) Students

A. Pre-Test
B. Post-Test
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Appendix K

Fall Semester 2008:
Geography 1900 (1p.m.) Students

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Fall Semester 2008:
Kalamazoo Valley Community College

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Alignment of Test Items with Modes of Spatial Thinking
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<td></td>
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<tr>
<td>Earth</td>
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<tr>
<td>Earth</td>
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Appendix N

Spatial Thinking Test

A. Pre-Test
B. Post-Test
My name is Kevin Weakley, and I am a Ph.D. Candidate in the Mallinson Institute for Science Education at Western Michigan University. I am conducting my dissertation research related to the effects of Geography 1900 on the spatial thinking of pre-service elementary teacher education students. The following exercises will assess your spatial thinking and ability at the beginning of Geography 1900.

You will have 30 minutes to complete the following spatial tasks. Answer the questions to the best of your ability. If you are completely uncertain about the answer, then respond to the 'Do not know' option. Do not guess. But, if you are somewhat certain, then mark the answer you think is correct. Do not spend too much time on one task, but pace yourself so that you can complete all tasks in 30 minutes. Thank you for your participation.
Directions: Rotate the standard shape to match the comparison shape.

1. a. Shape A.  
   b. Shape B.  
   c. Shape C.  
   d. Do not know

2. a. Shape A.  
   b. Shape B.  
   c. Shape C.  
   d. Do not know
3.
a.) Shape a
b.) Shape b
c.) Shape c
d.) Shape d
e.) Do not know

Instruction: From the array of four, choose that form that is identical to the target form.

4.
a.) Shape a
b.) Shape b
c.) Shape c
d.) Shape d
e.) Do not know

Instruction: From the array of four, choose that form which is a rotation of the target form.
5. The task is to identify the two figures on the left that are rotated versions of the target.
   a.) Figures 1, 2
   b.) Figures 2, 3
   c.) Figures 1, 3
   d.) Figures 3, 4
   e.) Do not know

6. The task is to indicate which of the five shaded shapes, when put together, would form the unshaded target shape.
   a.) Shapes 1, 3, 5
   b.) Shapes 2, 3, 4
   c.) Shapes 3, 4, 5
   d.) Shapes 1, 2, 3
   e.) Do not know

The task is to identify the object that is incompletely depicted.

7. The object is a(n) __________________________
DIRECTIONS: Answer question on the basis of the street map below.

8. If you are located at point 1 and travel north one block, then turn west and travel three blocks, and then turn south and travel two blocks, you will be closest to point:
   a.) 2  
   b.) 3  
   c.) 4  
   d.) 5  
   e.) 6  
   f.) Do not know

9. If you are located at point 1 and travel west one block, then turn left and travel three blocks, then turn west and travel one block, and then turn right and travel four blocks, you will be closest to point:
   a.) 2  
   b.) 3  
   c.) 4  
   d.) 5  
   e.) 6  
   f.) Do not know
11. If you draw a graph showing the change in annual precipitation between A and B, the most accurate graph will be _______.

12. What state is shown by the map?
   a.) Maine
   b.) Tennessee
   c.) Georgia
   d.) Texas
   e.) Do not know
13. Imagine you are standing at location X and looking in the direction of A and B. Select the profile which most closely represents what you would see.

![Map of Harpers Ferry with elevation profiles](image)

(A)  
(B)  
(C)  
(D)  
(E)  

14. Which geographic location on the map represents the highest elevation?
   a. Location A  
   b. Location B  
   c. Location X  
   d. Do not know
15. The climate of (A) is the most similar to what other location on the map ( )?

a. Climate (B)
b. Climate (C)
c. Climate (D)
d. Climate (E)
e. Do not know
16. Contour lines are lines of equal heights. Draw contour lines for every 50 foot beginning with the 550 contour line. In this way, your contour intervals should run 550, 600, 650, etc.
17. From the following temperature profile, which form of precipitation is likely to strike the surface? Hint: The vertical line is the freezing point, and the slanted line is the temperature profile. The temperature is above freezing to the right of the vertical line, and the temperature is below freezing to the left of the vertical line.

- a.) snow
- b.) rain
- c.) sleet
- d.) freezing rain
- e.) Do not know
18. Which of the following diagrams shows how the moon would look to a person standing at Point X on the Earth?

(a) 

(b) 

(c) 

(d) 

(e) I don't know.

19. From a view from above the Earth, which diagram shows how the Earth would appear at Point C?

(a) 

(b) 

(c) 

(d) 

(e) I don't know.
Research Post-Test

My name is Kevin Weakley, and I am a Ph.D. Candidate in the Mallinson Institute for Science Education at Western Michigan University. I am conducting my dissertation research related to the effects of Geography 1900 on the spatial thinking of pre-service elementary teacher education students. The following exercises will assess your spatial thinking and ability at the end of Geography 1900.

You will have 30 minutes to complete the following spatial tasks. Answer the questions to the best of your ability. If you are completely uncertain about the answer, then respond to the 'Do not know' option. Do not guess. But, if you are somewhat certain, then mark the answer you think is correct. Do not spend too much time on one task, but pace yourself so that you can complete all tasks in 30 minutes. Thank you for your participation.
1. If you draw a graph showing the change in annual precipitation between A and B, the most accurate graph will be _____.

(A) 

(B) 

(C) 

(D) 

(E) 

(F) 

2. What state is shown by the map?
   a.) Maine
   b.) Tennessee
   c.) Georgia
   d.) Texas
   e.) Do not know
3. Imagine you are standing at location X and looking in the direction of A and B. Select the profile which most closely represents what you would see.

![Map Diagram]

4. Which geographic location on the map represents the highest elevation?
   a. Location A
   b. Location B
   c. Location X
   d. Do not know
DIRECTIONS: Answer question on the basis of the map below.

5. The climate of (A) is the most similar to what other location on the map ( )?

a. Climate (B)
b. Climate (C)
c. Climate (D)
d. Climate (E)
e. Do not know
6. Contour lines are lines of equal heights. Draw contour lines for every 50 foot beginning with the 550 contour line. In this way, your contour intervals should run 550, 600, 650, etc.
7. From the following temperature profile, which form of precipitation is likely to strike the surface? Hint: The vertical line is the freezing point, and the slanted line is the temperature profile. The temperature is above freezing to the right of the vertical line, and the temperature is below freezing to the left of the vertical line.

- a.) snow
- b.) rain
- c.) sleet
- d.) freezing rain
- e.) Do not know
8. Which of the following diagrams shows how the moon would look to a person standing at Point X on the Earth?

- a. 
- b. 
- c. 
- d. 
- e. I don’t know.

9. From a view from above the Earth, which diagram shows how the Earth would appear at Point C?

- a. 
- b. 
- c. 
- d. 
- e. I don’t know.
Directions: Rotate the standard shape to match the comparison shape.

10.
a. Shape A.
b. Shape B.
c. Shape C.
d. Do not know

11.
a. Shape A.
b. Shape B.
c. Shape C.
d. Do not know
12. a.) Shape a  
   b.) Shape b  
   c.) Shape c  
   d.) Shape d  
   e.) Do not know

   Instruction: From the array of four, choose that form that is identical to the target form.

   Target form
   (a)  (b)  (c)  (d)

43. a.) Shape a  
   b.) Shape b  
   c.) Shape c  
   d.) Shape d  
   e.) Do not know

   Instruction: From the array of four, choose that form which is a rotation of the target form.

   Target form
   (a)  (b)  (c)  (d)
The task is to identify the two figures on the left that are rotated versions of the target.

a.) Figures 1, 2
b.) Figures 2, 3
c.) Figures 1, 3
d.) Figures 3, 4
e.) Do not know

The task is to indicate which of the five shaded shapes, when put together, would form the unshaded target shape.

a.) Shapes 1, 3, 5
b.) Shapes 2, 3, 4
c.) Shapes 3, 4, 5
d.) Shapes 1, 2, 3
e.) Do not know

The task is to identify the object that is incompletely depicted.

The object is a(n)
DIRECTIONS: Answer question on the basis of the street map below.

If you are located at point 1 and travel north one block, then turn west and travel three blocks, and then turn south and travel two blocks, you will be closest to point:

a.) 2 
b.) 3 
c.) 4 
d.) 5 
e.) 6 
f.) Do not know

If you are located at point 1 and travel west one block, then turn left and travel three blocks, then turn west and travel one block, and then turn right and travel four blocks, you will be closest to point:

a.) 2 
b.) 3 
c.) 4 
d.) 5 
e.) 6 
f.) Do not know