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## ANALYZING THE EFFECTS OF INQUIRY-BASED INSTRUCTION ON THE LEARNING OF ATMOSPHERIC SCIENCE AMONG PRE-SERVICE TEACHER EDUCATION STUDENTS

by

Robert James Ruhf

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

> Western Michigan University Kalamazoo, Michigan December 2006

## ANALYZING THE EFFECTS OF INQUIRY-BASED INSTRUCTION ON THE LEARNING OF ATMOSPHERIC SCIENCE AMONG PRE-SERVICE TEACHER EDUCATION STUDENTS

Robert James Ruhf, Ph.D.

Western Michigan University, 2006

This study tested whether or not pre-service teacher education students enrolled in inquiry-based earth science courses gained more thorough knowledge, comprehension, and application proficiencies with regard to atmospheric science concepts included in the Michigan Curriculum Framework for Science Education--the content standards of the Michigan State Board of Education for K-12--than did pre-service teacher education students enrolled in a traditionally-based earth science lecture/laboratory course. Content proficiencies were tested at the beginning of the semester (the pretest) and again at the end of the semester (the posttest). A sample of students participated in post-test interview sessions designed to examine in depth their knowledge, comprehension, and application proficiencies with regard to atmospheric science content. Classroom observation data related to the behavior of both students and instructors were collected and were later coded and analyzed using a lesson observation instrument that was based on Michigan and national teaching and learning.

Analysis of the pretest/posttests revealed that students in the traditional course demonstrated gains in knowledge and comprehension of content that resulted in statistically significant improvements on the overall posttest scores. Students in the inquiry-based courses accomplished some improvements in knowledge, comprehension and application proficiencies that did not result in statistically significant improvements on the overall posttest scores. The analysis of data suggests that the traditional course was more effective in preparing pre-service teachers to teach content consistent with the Michigan Curriculum Framework. The interpretation of the classroom observations and the interview sessions revealed that the inquiry-based courses were not fully consistent with national and state standards, included activities that did not adequately use investigative procedures, and lacked several major content areas outlined by the Michigan Curriculum Framework on which the pretest/posttest was based.

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Copyright by Robert James Ruhf 2006 In Loving Memory of my Father, Robert Franklin Ruhf For Believing in me When I Didn't Yet Know my Potential (December 8, 1934 - January 22, 2003)

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### Robert James Ruhf

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### CHAPTER I

#### PROBLEM STATEMENT

The objective of this study is to compare the effects of a pedagogical approach, that of inquiry-based instruction versus traditional, on achievement in atmospheric science among pre-service teachers enrolled in the elementary education program at Western Michigan University. Effect is defined and judged relative to the definitions and terms of the content standards established by the Michigan Curriculum Framework through the *Michigan Essential Goals and Objectives for Science Education* (Michigan State Board of Education, 1991, 2000) and *Clarifying Language in Michigan Benchmarks* (Michigan State Board of Education, 2004).

Published by the Michigan State Board of Education, the *Michigan Essential Goals and Objectives for Science* Education (MEGOSE) (Michigan State Board of Education, 1991, 2000) outlined the life, physical, and earth science "literacy" goals for the elementary, middle and high school grade levels. *Science literacy* was defined as "an understanding of those aspects of science that are essential for full participation in a democratic society," and it had the following three dimensions: *knowledge* (factual content), *activity* (construction of, reflection on, and use of knowledge), and *context* (application of knowledge to the real world). Specific benchmarks, referred to as "The Michigan Science Education Curriculum Framework" (Michigan State Board of Education, 1991, 2000) described what students should be able to do by the end of the 4<sup>th</sup> (elementary), 7<sup>th</sup> (middle school), and 12<sup>th</sup> (high school) grades. Those outcomes were provided within knowledge, activity, and context dimensions of science literacy.

*Clarifying Language in Michigan Benchmarks* (MI CLiMB) (Michigan State Board of Education, 2004) expanded upon the standards outlined in the MEGOSE. A

team of 52 science educators from across Michigan met for 16 days between March 2000 and May 2001 to draft and clarify standards for the content of life, physical, and earth science at the elementary, middle, and high school levels. Much of the benchmark language presented in the MEGOSE was contained within MI CLiMB, although minor modifications were made. All three dimensions of science literacy were included but were renamed as *benchmark*, *key concepts (vocabulary)/tools*, and *real-world context*. Each benchmark was followed by a "benchmark clarification" that was worded in language specifically for teachers. Additional clarifications for each benchmark were provided by the inclusion of two additional sections: (1) an instructional example along with resources and links to the constructing and reflecting benchmarks used to facilitate the instruction, and (2) an assessment example and a grading tool. An example of these clarifications outlined within MI CLIMB is in Appendix A.

Five main areas (referred to as "strands") of science were emphasized within the MI CliMB. "Strand V" outlined the content standards related to Earth and Space Sciences. The third content standard within the strand directly addressed atmospheric sciences. It stated:

Content Standard 3: All students will investigate and describe what makes up weather and how it changes from day to day, from season to season, and over long periods of time; explain what causes different kinds of weather, and analyze the relationships between human activities and the atmosphere.

The elementary and middle school benchmarks, benchmark clarifications, key concepts, and related real world contexts in the content standards are in Appendix B.

All students enrolled in 100-level courses designed by the Mallinson Institute for Science Education at Western Michigan University are preparing to be elementary school teachers. Several years ago, faculty members within the Institute, then known as the Department of Science Studies, observed that many pre-service teachers were graduating without the level of understanding needed to teach science according the standards of the Michigan Curriculum Framework. It was hypothesized that traditional science courses (which focused on lectures, memorization, and pre-structured lab experiments) discouraged reflective and critical thinking, the underlying goals of the Michigan science content standards. All 100-level courses within the department were therefore restructured to an "inquiry-based" format that emphasized hands-on experiences. No lectures were to be presented in these newly designed courses. Rather, instructors were to function as guides, and students were to learn the principles of science through various classroom activities that incorporated inquiry.

The hypothesis for the study is: Pre-service elementary teachers enrolled in the inquiry-based earth science courses designed by the Mallinson Institute for Science Education will not demonstrate a statistically significant difference in their understanding of and proficiencies with atmospheric science concepts that are included in the Michigan Curriculum Framework for Science Education—the content standards of the Michigan State Board of Education—than will pre-service elementary teachers and general education students enrolled in a physical geography lecture/laboratory course offered by the Geography Department.

*Inquiry* is defined as an instructional and learning approach that is consistent with the definitions and guidelines for inquiry provided by the National Science Education Standards (National Research Council, 1996), the National Geography Standards (Geography Education Standards Project, 1994), and the Michigan Curriculum Framework (Michigan State Board of Education, 1996). These definitions and guidelines are summarized in the "Inquiry and current science education standards" section of Chapter Two.

*Traditional* is defined as an approach that emphasizes lecture-oriented instruction and the rote learning of factual content. Laboratory activities are usually pre-structured experiments that are designed to confirm the content presented in the lectures.

*Understanding* is defined as the ability to explain observable, physical phenomena in ways that are consistent with the content standards outlined by the Michigan Curriculum Framework.

Content proficiencies among students enrolled in either traditional or inquirybased earth science courses were tested at the beginning of meteorology units (the pretest) and again at the end of meteorology units (the posttest) for atmospheric science concepts emphasized by the Michigan Curriculum Framework for Science Education. A random sample of students also participated in an interview session designed to examine in-depth their proficiencies with atmospheric science.

Significant information about the effect of the inquiry approach to pre-service teacher education at Western Michigan University will be provided by this study. The Mallinson Institute for Science Education currently supervises inquiry-based courses in Physics, Biology, Chemistry, Geography, and Geosciences. Whether these courses are more effective than traditional science courses was the question that remained, and is investigated in part by this study. Do these inquiry-based courses better prepare preservice elementary teachers to teach the Earth and Space Sciences content standards established by the State of Michigan? The purpose of the proposed study is to answer this question for atmospheric science content. This is the first in-depth study completed to answer this question for a course designed by the Institute.

Very little research has been conducted about the effect of the inquiry approach to pre-service teacher education. Specialized courses for pre-service teachers have been designed at several Universities across the country to engage students in inquiry (Friedrichsen, 2001; Jones, 1997; McLoughlin, 1999; O'Haver, 1997), but the impact of these courses has only been assessed through qualitative interpretations. This will be further explained in the next chapter. If such courses are to continue to be created, it is important to assess their effectiveness and to assess the effectiveness of the inquiry approach in general. This study therefore has broad implications for science education

outside of the Mallinson Institute for Science Education at Western Michigan University. The research conducted here could serve as a model for research conducted at other universities.

#### CHAPTER II

#### BACKGROUND

#### Inquiry and the Curriculum Reform Movement

The communist government of the Union of Soviet Socialist Republics (USSR) launched Sputnik, the first artificial satellite to orbit the earth, in October of 1957. The impact on the free world was comparable to a shockwave. Sputnik's "relentless beep distressed Americans, reminding them that the Soviets had won the race to space with the first-ever successful launch of a satellite. The Americans' failed attempt two months later with a much smaller satellite that blew up on the launch pad didn't help reduce feelings of loss" (Biological Sciences Curriculum Study, 2006; p.1). Critics were very quick to accuse the United States of "falling behind the Soviets in science and technology education (Biological Sciences Curriculum Study, 2006; p. 1). Scientific curriculum reform efforts, led by the National Science Foundation (NSF) were "subsequently pushed into the spotlight as the best hope for recovering U.S. educational preeminence" (Rudolf, 2002, p. 84). These efforts "signaled the onset of cooperative efforts between specialists in discipline areas and specialists in education to improve teaching" (Kirschner, et. al., 2004; p. 15) that led to over "two decades of federal involvement in science teaching and the development of an approach to science education that was focused on the logical structure of the disciplines and on the processes of science" (DeBoer, 1991; p. 147).

The earliest effort occurred within the discipline of Physics and was initiated by the Physical Science Study Committee (PSSC) "prior to the launching of *Sputnik* at the Massachusetts Institute of Technology under the directorship of J. R. Zacharias" (Poel, 1970, p. 20). Zacharias "applied to the National Science Foundation for funding and

received approval for the...project" (DeBoer, 1991; p. 148). During the course of the next two decades, similarly focused elementary and secondary school curricula were developed for other disciplines of science. This was performed on such a large scale that this time period has been described as the "golden age" of science and mathematics education (Bybee, 1997; p. 1). In fact, "school science curricula experienced [such] considerable growth and substantial change [that it] can be described only as 'phenomenal'" (Shymansky, et. al., 1983; p. 387). The National Science Foundation (NSF) "supported [an] explosion of 'alphabet soup curricula' in the late 1950s and early 1960s" (Matthews, 1994; p. 17) that included the Biological Sciences Curriculum Study (BSCS), the Chemical Bond Approach (CBA), the Chemical Education Materials Study (CHEMS), the Earth Science Curriculum Project (ESCP), Introductory Physical Science (IPS), and Project Physics. For the elementary level, "there was the Elementary Science Study, known as ESS; the Science Curriculum Improvement Study, known as SCIS, and Science — A Process Approach, known as S-APA" (Bybee, 1997, p. 2). In fact, "by 1975, the NSF supported twenty-eight science curriculum reform projects" (Matthews, 1994; p.17).

The structure of the reform movement was such that instead of having one set of goals, there were many. Each curriculum project [was] "free to formulate objectives for its own particular segment of the curriculum" (Goodlad, 1964; p. 11). Thus, "a comprehensive set of goals and objectives was never thoroughly articulated" (Shymansky, *et. al.*, 1983; p. 388). Nonetheless, the curriculum reform movement was generally characterized by certain features that are important within the context of this study.

At the start, the reformers placed a strong emphasis on the role of inquiry in the learning of science. All curricula were "designed with new rationales for both education in general and the use of practical experience, such as science laboratories in particular, and were meant to promote meaningful learning and learning by doing" (Kirschner *et. al.*,

2002, p. 14). Joseph Schwab, the first director of the Biology Sciences Curriculum Study, asserted that "science education should be designed so that learning is an 'enquiry into enquiry' and not a rhetoric into conclusions, e.g., teaching what we know" (Duschl & Grundy, 2005; p. 6). Learning was therefore portrayed as being an active process in which students do more than simply take in knowledge presented by teachers (Schwab, 1962; p. 66):

[The aim of a completely enquiring classroom] is not only the clarification and inculcation of a body of knowledge but the encouragement and guidance of a process of discovery on the part of the student. For the student, this means relinquishment of habits of passivity, docile learning, and dependence on teacher and textbook, in favor of active learning in which lecture and textbook are challenged.

Reformers were committed to the notion that "students should be provided with opportunities to engage with phenomena, that is to probe the natural world and conduct inquiries that would reveal patterns of nature and the guiding conception of science" (Duschl & Grundy, 2005; p 6). The classroom laboratory was regarded as the ideal place where this could be accomplished. The Physical Science Study Committee (PSSC), for example, saw the classroom laboratory as providing "the hands-on experience with natural phenomena [that was] essential for a complete understanding of the rational basis of scientific thinking" (Rudolf, 2002; p. 129). The Biological Sciences Curriculum Study (BSSC) envisioned the classroom laboratory abandoning "cut-and-dried experiments in order to involve students in discovery" (Goodlad, 1964; p. 26). The Chemical Bond Approach Committee (CBA) viewed classroom laboratory experiments as "puzzles to be solved" (Welch, 1979; p. 290).

Overall, it was the goal of curriculum reformers to "downsize the role of the textbook in science teaching and elevate the role of investigative and laboratory experiences in science classrooms" (Duschl & Grundy, 2005; p. 6). Within this context, a high value was placed on classroom discussions. Joseph Schwab asserted that "many

questions have no 'right' answer, but only more probable answers or more and less defensible answers" (Schwab, 1962; p. 70). As such, "the aim of criticism and defense of alternative answers is not to 'win the argument' but to find the most defensible solution to a problem" (Schwab; p. 70). A classroom discussion was therefore viewed as a "powerful mode of learning" (DeBoer, 1991; p. 165).

Another major characteristic of the curriculum reform movement was a philosophical shift "away from teaching a discipline as a body of knowledge towards an exclusive emphasis on the experience of the processes and procedures of the discipline" (Kirschner, et. al., 2004; pp. 14-15). Focusing on discovery and inquiry methods of learning led curriculum reformers to reject instruction "based on facts, laws, principles and theories that made up a disciplines' content" (Kirschner, et. al., 2004; p. 15). The new science curricula "came to be associated with process objectives where learning how to learn science was stressed" (Shymansky, et. al., 1983; p. 388). It was believed that "science classes should teach science; not isolated facts, not the history of technology, but an understanding of the major ideas of science and the process by which these ideas are advanced" (Novak, 1964; p. 6). Science – A Process Approach (S-APA), for example, was an elementary school science curriculum program developed during the Summer of 1963 that envisioned children benefiting from the learning of process skills during their "earlier years of elementary schooling" (Goodlad, 1964; p. 40). The fundamental assumptions that guided this program typify the attitudes of the time (Goodlad, 1964; p. 40):

[Science] is much more than a simple encyclopedic collection of facts, and...children in the primary grades can benefit from acquiring certain basic skills and competencies essential to the learning of science. These competencies have been identified as follows: observation, classification, recognition and use of space-time relations, recognition and use of numbers and number relations, measurement, communication, inference, and prediction. The expectation is that the ability to use scientific processes will remain after many of the details of science will be forgotten. These competencies are advocated as appropriate for virtually all levels of science education and are not confined to the primary grades.

Such a passionate focus on the processes of science often resulted in the presentation of fewer topics, but to a much greater depth than what had been covered before the reform movement. The Physical Science Study Committee (PSSC), for example, focused on the "fundamental concepts of physics over the usual emphasis on the mass of factual information so often included in high school physics courses... Teaching fewer topics in greater depth would be key...to helping students develop a deep understanding of the discipline" (Rudolf, 2002; 115). While traditional physics classes had attempted to "cover the requirements of standard state and local syllabi and examinations" (Trowbridge, 1965; p. 117) and to study "mechanics, heat, sound, light, magnetism, electricity, electronics, atomic structure, [and], nuclear energy" (Trowbridge, 1965; p. 118), the Physical Science Study Committee (PSSC) attempted to "emphasize the study of a few major topics at a considerable depth" (Trowbridge, 1965; p. 118), and that "from the standpoint of their contributions to physics as a pure science" (Trowbridge, 1965; p. 118).

As the Cold War ended and the communist empire of the Soviet Union crumbled away, public and government support for the curriculum reform programs disappeared. The large amounts of money needed "for continued development of science programs [had] been withdrawn and public sentiment apparently [favored] a move back to the basics" (Shymansky, *et. al.*, 1983, p. 388). Matthews (1994; p. 18) explains that the "times had changed; the Soviet threat had receded, the US had its man on the moon, school enrollments were falling, and there was a state and local authority backlash against the *de facto* introduction of a national curriculum—such federal interference was (and still is) a matter of grave concern to the over 16,000...independent school boards in the US."

The philosophies that governed the reform movement even began to receive criticism from the science education community. Matthews (1994) suggested that the "failure" of inquiry as it was expressed in the 1960s can be attributed to a number of questionable or false assumptions within the intellectual foundations of the approach, including the notions that "a child in isolation can discover and vindicate scientific truths...[and that] the language and concepts required for hypothesis development can be acquired independently of teachers, or, more generally, independently of social interactions, and participation in language communities" (p. 147). Similarly, Hodson (1988) argued that the process approach and the discovery-learning approach failed to take into consideration certain factors that influence understanding, such as pre-existing knowledge structures held by the learners (p. 61):

The so called 'process approach' to learning science does have the great virtue of requiring the learners to be active, but it ignores the influence of children's existing ideas on how the processes are employed and conclusions reached. It assumes that the processes of science are content-free, generalizable and transferable from one context to another. In asserting the priority of process over concepts, it implies an inductivist model of science. The discovery-learning approach, a prominent feature of science curricula developed in the 1960s and 1970s is similarly discredited from philosophical, psychological, and practical perspectives.

Several other explanations for the failure of the curriculum reform movement were summarized by Domin (1999, pp. 544-5). Kohlberg & Gilligan (1971) believed that "the inquiry activities 'assumed formal operational thought rather than attempting to develop it" (Domin, 1999, p. 544). Linn (1977) argued that the movement "placed too much demand on the learner's short-term memory by requiring students to simultaneously attend to new subject matter concepts, unfamiliar laboratory equipment, and novel problem-solving tasks" (Domin, 1999, p. 544). Herron (1971) and Tamir & Lunetta (1978) observed that "the manner in which the inquiry-based activities were employed did not allow the students opportunities to practice and develop such important inquiry skills as defining a research problem, formulating hypotheses, planning an experiment, and identifying limitations" (Domin, 1999, p. 555). Duschl (1985, 1990) argued that "at the same time science education was adopting the perspective of teaching science as an 'inquiry into inquiry,' the basic definition of inquiry was changing from only learning how to test knowledge claims to also explaining and evaluating these knowledge claims" (Domin, 1999; p. 555). Friedl (1991) argued that the curriculum reform movement placed "too much emphasis on the scientific process and not enough on science content" (Domin, 1999; p. 555).

There is evidence, however, that the curriculum reform movement was characterized by significant successes. Shymansky, *et. al.* (1983) employed a *metaanalysis* (Glass, 1976), a "quantitative synthesis perspective to research integration" (Shymansky, et. al., 1983; p. 387), to synthesize the results of 105 studies involving 27 curriculum projects and 45,626 students. The researchers observed that, across all curricula, students "performed better than students in traditional courses in general achievement, analytic skills, process skills, and related skills (reading, mathematics, social studies and communication), as well as developing a more positive attitude toward science" (Shymansky, *et. al.*, 1983; p. 387). Thus, in spite of its shortcomings, the curriculum reform movement successfully emphasized an inquiry-oriented approach to learning the processes of science, and has helped to construct a foundation upon which many of the current science education standards are based.

#### Inquiry and the Current Science Education Standards

The inquiry-based principles that guided the curriculum reform movement of the 1950s and 1960s remain important to many science educators of today. In response to the shortcomings of the curriculum reform period, however, the definitions and

understandings of inquiry have changed significantly (DeBoer, 1997; "What Have We Learned," paragraph 4):

During the reform movement of the 1960s there was the tendency to define inquiry quite precisely in terms of a set of process skills, often with the implication that these skills could be learned independently of the content of science. Today, inquiry...is presented as a much more general process of investigation, both as conducted by scientists and by students in the classroom.

Inquiry within this broader and more flexible context has had a significant role in the drafting of several current science education standards. The following section will describe this role within the framework of three sets of standards that are important within the context of this study.

#### The National Science Education Standards

The National Science Education Standards (National Research Council, 1996) were published in 1996 in order to enable the nation to achieve the goal of science literacy for all students. These standards claim to "emphasize a new way of teaching and learning about science that reflects how science itself is done, emphasizing inquiry as a way of achieving knowledge and understanding about the world" (National Research Council, 1996; p. ix). Inquiry has meaning not only within the context of scientific research, but also within the context of the science classroom (National Research Council, 1996; p. 23):

Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.

The standards present inquiry as a "multifaceted activity" that involves "making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and perspectives, and communicating the results" (National Research Council, 1996; p. 23). These activities require students to identify assumptions, make use of critical and logical thinking skills, and consider alternative explanations (National Research Council, 1996; p. 23). Although inquiry is *emphasized* by these standards, it is by no means presented as the *only* approach to science teaching. In fact, it is recommended that teachers use "different strategies to develop the knowledge, understandings, and abilities described in the content standards" (National Research Council, 1996; p. 23). It is also noted that the conducting of "hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry" (National Research Council, 1996; p. 23).

The standards for inquiry are divided into categories that "highlight the ability to conduct inquiry and develop understanding about scientific inquiry" (National Research Council, 1996, p. 105) for the grade levels of K-4, 5-8, and 9-12.

For the K-4 grade level, the abilities that should be developed to do scientific inquiry include (National Research Council, 1996; p. 122):

- 1. Ask a question about objects, organisms, and events in the environment.
- 2. Plan and conduct a simple investigation.
- 3. Employ simple equipment and tools to gather data and extend the senses.
- 4. Use data to construct a reasonable explanation.
- 5. Communicate investigations and explanations.

Areas of scientific understanding that should be developed at this grade level include

(National Research Council, 1996; p. 124):

- 1. Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world.
- 2. Scientists use different kinds of investigations depending on the questions they are trying to answer. Types of investigations include

describing objects, events, and organisms; classifying them; and doing a fair test (experimenting).

- 3. Simple instruments, such as magnifiers, thermometers, and rulers, provide more information than scientists obtain using only their senses.
- 4. Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge). Good explanations are based on evidence from investigations.
- 5. Scientists make the results of their investigations public; they describe the investigations in ways that enable others to repeat the investigations.
- 6. Scientists review and ask questions about the results of other scientists' work.

For the 5-8 grade level, the abilities that should be developed to do scientific

inquiry include (National Research Council, 1996; pp. 145, 148):

- 1. Identify questions that can be answered through scientific investigations.
- 2. Design and conduct a scientific investigation.
- 3. Use appropriate tools and techniques to gather, analyze and interpret data.
- 4. Develop descriptions, explanations, predictions, and models using evidence.
- 5. Think critically and logically to make the relationships between evidence and explanations.
- 6. Recognize and analyze alternative explanations and predictions.

Areas of scientific understanding that should be developed at this grade level include

(National Research Council, 1996; p. 148):

- 1. Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.
- 2. Current scientific knowledge and understanding guide scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding.
- 3. Mathematics is important in all aspects of scientific inquiry.
- 4. Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
- 5. Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories. The

scientific community accepts and uses such explanations until displaced by better scientific ones. When such displacement occurs, science advances.

- 6. Science advances through legitimate skepticism. Asking questions and querying other scientists' explanations is part of scientific inquiry. Scientists evaluate the explanations proposed by other scientists by examining evidence, comparing evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations.
- 7. Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data. All of these results can lead to new investigations.

For the 9-12 grade level, the abilities that should be developed to do scientific

inquiry include (National Research Council, 1996; pp. 175-176):

- 1. Identify questions and concepts that guide scientific investigations.
- 2. Design and conduct scientific investigations.
- 3. Use technology and mathematics to improve investigations and communications.
- 4. Formulate and revise scientific explanations and models using logic and evidence.
- 5. Recognize and analyze alternative explanations and models.
- 6. Communicate and defend a scientific argument.

Areas of scientific understanding that should be developed at this grade level include

(National Research Council, 1996; p. 176):

- 1. Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.
- 2. Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.
- 3. Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.

- 4. Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, and constructing explanations and communicating results.
- 5. Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modifications; and it must be based on historical and current scientific knowledge.
- 6. Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and processes that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation.

#### The National Geography Standards

Another set of national standards that stress the importance of inquiry are the National Geography Standards (Geography Education Standards Project, 1994). Published under the title Geography for Life: What Every Young American Should Know and Be Able to Do in Geography, these standards "identify what American students should learn—a set of voluntary benchmarks that every school and school district may use as guidelines for developing their own curricula" (Geography Education Standards Project, 1994; p. 9). The stated purpose of these standards is to "bring all students up to internationally competitive levels to meet the demands of a new age and a different world" (Geography Education Standards Project, 1994; p. 9). It is asserted that these standards "provide every parent, teacher, curriculum developer, and business and political leader with a set of challenging expectations for all students" (Geography Education Standards Project, 1994; p. 9). Five essential steps representing the process of geographic inquiry are presented, all of which were adapted from Guidelines for Geographic Education: Elementary and Secondary Schools published by the Joint Committee on Geographic Education of the National Council for Geographic Education and Association of American Geographers (1984).

The first step of geographic inquiry involves asking geographic questions. Successful geographic inquiry "involves the ability and willingness to ask, speculate on, and answer questions about why things are where they are and how they got there. Students need to be able to pose questions about their surroundings" (Geography Education Standards Project, 1994; p. 42). A way to approach this involves "giving students practice in distinguishing geographic from non-geographic questions and by presenting students with issues and asking them to develop geographic questions" (Geography Education Standards Project, 1994; p. 42).

The second step of geographic inquiry involves acquiring geographic information. In order to begin the process of answering geographic questions, it is necessary for students to acquire geographic information in various ways and from various sources. Specific skills that are involved in this process include "locating and collecting data, observing and systematically recording information, reading and interpreting maps and other geographic representations of spaces and places, interviewing, and using statistical methods" (Geography Education Standards Project, 1994; p. 42-43). Fieldwork is an essential element (Geography Education Standards Project, 1994; p. 43):

Primary sources of information, especially the result of field work performed by the students, are important in geographic inquiry... Fieldwork helps arouse the students' curiosity and makes the study of geography more enjoyable and relevant. It fosters active learning by enabling students to observe, ask questions, identify problems, and hone their perceptions of physical features and human activities. Fieldwork connects students' activities with the world in which they live.

The third step of geographic inquiry involves organizing geographic information. Acquired geographic information must be organized and presented in ways that help with the analysis and interpretation of the information. Maps play a "central role" in the process of geographic inquiry; but graphs, tables, spreadsheets and time lines are also important ways to translate data into visual form (Geography Education Standards Project 1994, p. 43). It is noted that visuals become especially important when they are accompanied by oral or written summaries, and that some level of creativity is involved (Geography Education Standards Project 1994, p. 43):

Creativity and skill are needed to arrange geographic information effectively. Decisions about design, color, graphics, scale, and clarity are important in developing the kinds of maps, graphs, and charts that best reflect the data.

The fourth step of geographic inquiry involves analyzing geographic information. This entails "seeking patterns, relationships, and connections. As students analyze and interpret information, meaningful patterns or processes emerge. Student can then synthesize their observations into a coherent explanation" (Geography Education Standards Project, 1994; p. 43). A variety of activities are involved in this step, including scrutinizing maps to "discover and compare spatial patterns and relationships;" studying tables and graphs "to determine trends and relationships between and among items;" probing data "through statistical methods to identify trends, sequences, correlations, and relationships; and examining "texts and documents to interpret, explain, and synthesize characteristics" (Geography Education Standards Project, 1994; p. 43-44). When taken together, these analytic processes "lead to answers to the questions that first prompted an inquiry" (Geography Education Standards Project, 1994; p. 43).

The fifth step of geographic inquiry involves answering geographic questions. The culmination of successful geographic inquiry is the "development of generalizations and conclusions based on the data collected, organized, and analyzed" (Geography Education Standards Project, 1994; p. 44). Skills associated with this step include "the ability to make inferences based on information organized in graphic form (maps, tables, graphs) and in oral form and written narratives" (Geography Education Standards Project, 1994; p. 44). It is also expected that students will be able to "distinguish generalizations that apply at the local level from those that apply at the global level (issues of scale are important in developing answers to geographic questions)" (Geography Education Standards Project, 1994; p. 44).

#### The Michigan Curriculum Framework

A set of standards at the state level that emphasize the importance of inquiry are found within the Michigan Curriculum Framework (Michigan State Board of Education, 1996). Although inquiry is never mentioned within Strand V of the *Michigan Essential Goals and Objectives for Science Education* (MEGOSE) (Michigan State Board of Education, 1991, 2000) or *Clarification Language in Michigan Benchmarks* (MI CLiMB) (Michigan State Board of Education, 2004), it is addressed in Strand V of the Social Studies Standards (Michigan State Board of Education, 1996; p. 41):

Inquiry: Students will use methods of social science investigations to answer questions about society.

While this presentation of inquiry is formulated within the context of the social sciences, many of the general principles can be applied to the natural sciences.

The Social Studies Standards describe inquiry as an "essential component of decision-making" that is necessary for "citizens to make sound decisions in efforts to solve social problems" (Michigan State Board of Education, 1996; p. 41). Students, who are also citizens, "must learn how to pursue data, think critically, and communicate their findings effectively" (Michigan State Board of Education, 1996; p. 41).

The Social Studies Standards state that inquiry involves the learning of two procedures. These are presented as content standards for "information processing" and "conducting investigations."

Four vital skills are addressed within the "information processing" standard. First, students should develop the ability to acquire information from a variety of sources, including newspapers, data sets, books, and maps. Second, students should learn how to use various means to organize and present information, such as time lines, charts, maps, and graphs. Third, students should understand how to interpret the meaning of information and be able explain why the information is significant. Fourth, students should know how to access and manage information through various electronic
technologies such as computers, media, and telecommunication technology (Michigan

State Board of Education, 1996; p. 41).

Early elementary benchmarks for this content standard include (Michigan State

Board of Education, 1996; p. 55):

- 1. Locate information using people, books, audio/video recordings, photos, simple maps, graphs, and tables.
- 2. Acquire information from observation of the local environment.
- 3. Organize information to make and interpret simple maps of their local surroundings and simple graphs and tables of social data drawn from their experience.

Later elementary benchmarks for this content standard include (Michigan State Board of

Education, 1996; p. 55):

- 1. Locate information about local, state, and national communities using a variety of traditional sources, electronic technologies, and direct observations.
- 2. Organize social science information to make maps, graphs and tables.
- 3. Interpret social science information about local, state, and national communities from maps, graphs, and charts.

Middle school benchmarks for this content standard include (Michigan State Board of

Education, 1996; p. 55):

- 1. Locating and interpret information about the natural environments and cultures of countries using a variety of primary and secondary sources and electronic technologies, including computers and telecommunications where appropriate.
- 2. Use traditional and electronic means to organize social science information and to make maps, graphs, and tables.
- 3. Interpret social science information about the natural environment and cultures of countries from a variety of primary and secondary sources.

High school benchmarks for this content standard include (Michigan State Board of

Education, 1996; p. 55):

- 1. Locate information pertaining to a specific social science topic indepth using a variety of sources and electronic technologies.
- 2. Use traditional and electronic means to organize and interpret information pertaining to a specific social science topic and preparing information for in-depth presentation.

3. Develop generalizations pertaining to a specific social science topic by interpreting information from a variety of sources.

Additional skills are addressed within the "conducting investigations" standard.

These include the formulation of "a clear statement of a question, gathering and

organizing information from a variety of sources, analyzing and interpreting information,

formulating and testing hypotheses, reporting results both orally and in writing, and

making use of appropriate technology (Michigan State Board of Education, 1996; p. 41).

It is also stated that "investigations can be carried out by individuals or groups"

(Michigan State Board of Education, 1996; p. 41).

Early elementary benchmarks for this content standard include (Michigan State

Board of Education, 1996; p. 55):

- 1. Pose a question about life in their school or local community.
- 2. Gather and analyze information in order to answer the question posed.
- 3. Construct an answer to the question posed and supporting that answer with evidence.
- 4. Report the results of their investigation.

Later elementary benchmarks for this content standard include (Michigan State Board of

Education, 1996; pp. 55-56):

- 1. Pose a social science question about Michigan or the United States.
- 2. Gather and analyze information using appropriate information technologies to answer the question posed.
- 3. Construct an answer to the question posed and supporting their answer with evidence.
- 4. Report the result of their investigation including the procedures followed.

Middle school benchmarks for this content standard include (Michigan State Board of

Education, 1996; pp. 55-56):

- 1. Pose a social science question about a culture, world region, or international problem.
- 2. Gather and analyze information using appropriate information technologies to answer the question posed.
- 3. Construct an answer to the question posed and supporting their answer with evidence.

4. Report the result of their investigation including procedures followed and possible alternative conclusions.

High school benchmarks for this content standard include (Michigan State Board of

Education, 1996; p. 55):

- 1. Conduct an investigation prompted by a social science question and comparing alternative interpretations of their findings.
- 2. Report the results of their investigation including procedures followed and a rationale for the conclusions reached.

# Summary Statement

There are a number of similarities among the inquiry statements presented above from the physical and geography/social sciences. In review, the broader umbrella of inquiry includes the following:

- 1. Asking and formulating problem-based questions.
- 2. Designing and conducting methods and procedures (experiments) for answering questions or solving problems.
- 3. Collecting, using, and analyzing various forms of data.
- 4. Using mathematics and technology as tools for discovery.
- 5. Evaluating what qualifies as evidence and what does not.
- 6. Revising and rethinking existing ideas.
- 7. Making connections and constructing logical arguments.
- 8. Formulating and communicating answers based on the outcomes of the experiment.
- 9. Validating results.
- 10. Considering alternative ideas and solutions.

The presence of any of these elements does not guarantee that students are

engaged in inquiry-based learning. Rather, it is the collection of these elements practiced

consistently with how they have been defined within the standards that determines

whether students are engaged in authentic investigative processes.

Inquiry and Pre-Service Teachers

There is a dramatic difference between how the majority of pre-service teachers

experience introductory science classes and how the standards outlined above

recommend that they should be experienced (Wilden, et. al., 2002; p. 1):

Halls are filled with a hundred or more students listening to lectures. Smaller groups participate in prescriptive labs that seldom relate learning to the daily life of the student. The experience that the majority of students have after such a course is that of listening to many hours of lecture, reading, and memorizing material from a text. These courses are generally designed for the non-science major; those who will be future writers, social workers, and artists. However, these courses are also where most of the future elementary educators in this country will learn the science concepts they will be expected to teach in their own classrooms.

It seems unlikely that "elementary education majors are receiving the education suggested in the [National Science Education] standards through participation in the traditional lecture and laboratory format classes" (Wilden, *et. al.*, 2002; p. 1). New classes for elementary educators should therefore be designed to insure "that the subject matter being taught in the classroom reflects the subjects that the students will eventually teach in their own classrooms" (Wilden, *et. al.*, 2002; p. 2). These classes should be designed with the cooperative efforts of science educators and science professors, as science professors "would not be expected to be experts on the newest and most effective teaching practices in elementary education (K-8), nor would one who specializes in education be expected to be expert at all of the disciplines of science" (Wilden, *et. al.*, 2002; p. 2). Such specialized science courses have been created through the collaborative efforts of various departments at several universities. Five such examples are presented in this section, most of which were at least partially influenced by the drafting of the National Science Education Standards (National Research Council, 1996).

### The University of Maryland

A first-year undergraduate introductory chemistry course at the University of Maryland was redesigned "under the sponsorship of the Maryland Collaborative for Teacher Preparation to improve the pre-service preparations of science and mathematics teachers for grades 5-8" (O'Haver, 1997; p. 522). Enrollment in the course was not restricted to pre-service teachers.

There were at least four ways that this course differed from the design of the traditional introductory chemistry course. First, the number of topics presented was reduced. This was done "in order that students might attain a greater degree of understanding of the concepts studied" (O'Haver, 1997; p. 522). Second, the class schedule was changed from three one-hour lectures and one laboratory session per week to three two-hour sessions each week. This allowed for "greater flexibility depending on the topic and the students' progress; sometimes the class would meet for several successive class periods in the laboratory, in the computer laboratory, or in the regular classroom" (O'Haver, 1997; p. 522). Third, in order to maintain consistency with the "goal of actively engaging the students in the study of Chemistry" (O'Haver, 1997; p. 522), lectures were not used as a means of instruction. Most of the time was spent devoted to "small-group cooperative activities that involved working with information sources, data, observations, manipulatives, computer-based activities, or laboratory experiments, interspersed with small-group and whole-class discussion" (O'Haver, 1997; p. 522). Fourth, the use of technology was given a greater role. Spreadsheets were introduced "as an approach to complex multistep quantitative problem solving and graphical data display" (O'Haver, 1997; p. 522), nomenclature software and molecular modeling software were used to "develop students' ability to visualize and work with bonding and 3-dimensional structures (O'Haver, 1997; p. 522), and the Internet "was integrated into two of the experiments" (O'Haver, 1997; p. 522).

Significant changes were made for how students' understandings were tested. The multiple-choice test format was discarded in favor of an essay and word problem format. Students were also asked during the last class activity to list the "most important concepts and skills developed in the course" (O'Haver, 1997; p. 522) and to create test questions to "assess mastery of those skills and concepts…with the promise that the most

suitable questions would be used on the final examination" (O'Haver, 1997; p. 522). Questions that tested factual recall were not considered suitable.

### The University of Nebraska-Lincoln

A specialized biology course to meet the needs of pre-service teachers was designed through the collaborative efforts of the School of Biological Sciences and the Teachers College at the University of Nebraska-Lincoln in 1994 "to improve prospective elementary teachers' attitudes toward science and increase self-efficacy in science teaching" (Friedrichsen, 2001; p. 562). However, the goals of the course were reexamined after the publication of the National Science Education Standards (National Research Council, 1996). The course was re-designed during the summer of 1997 in order to align the curriculum, instruction and assessment "more closely with the Standards" (Friedrichsen, 2001; p. 562).

There were at least three ways that this course differed from a typical biology course. First, the course met only twice per week, the first session for a two-hour time period and the second session for a three-hour time period. Second, the enrollment was capped at only 24 students. Third, all students were assigned to work in "learning teams" (Friedrichsen, 2001; p. 562) that consisted of four students who worked together on inquiry-oriented investigations and projects, including several long-term projects. Freshmen and upperclassmen were included on the same teams in order "to facilitate informal peer mentoring within the Elementary Education Program" (Friedrichsen, 2001; p. 562).

The instructional strategies employed by the course were based primarily on two inquiry-based instructional models: the 4-E Science Learning Model (Martin, *et. al.*, 1997; pp. 303-311) and the Circle of Inquiry Model (Haury, 1997). These models are described as follows (Friedrichsen, 2001; p. 563):

The 4-E Science Learning Cycle Model...consists of phases of exploration, explanation, expansion and evaluation. In the exploration phase, students interact with biological materials, making observations and asking questions... In the explanation phase, the instructors lead the students in a discussion to develop the biological concept... In the expansion phase, students return to the biological materials and apply the biological concept in a new way... The fourth phase is evaluation, which is ongoing and occurs throughout the 4-E Learning Cycle...

Haury's Circle of Inquiry Model was designed for use with elementary age children and provides an alternative to the linear, step-wise scientific method that many of our students had memorized but few had actually experienced in science courses. The Circle of Inquiry Model has four components: wondering, collecting data, studying data and making connections... The model has no set entry point, but we tend to engage our students in inquiry by asking them to make observations of particular living material. We found that the Circle of Inquiry Model fosters students' curiosity. Our students gained confidence in their ability to ask testable questions and to investigate those questions. The Circle of Inquiry Model represents science as an ongoing process of inquiry.

Several questions related to the National Science Education Standards (National

Research Council, 1996) were formulated to assist in the re-designing of the course.

These questions were asked in order to ensure that the course would "continue to be

relevant to the future needs of prospective elementary teachers" (Friedrichsen, 2001; p.

564):

- 1. Does the...course reflect the unifying concepts and processes of science as outlined by the NSES [National Science Education Standards]?
- 2. Does the...course reflect the unifying concepts and processes of science as outlined by the NSES?
- 3. Does the course curricula reflect the NSES inquiry content standards?
- 4. How can extended inquiry projects be included to represent the nature of research in biology?
- 5. Does the biology content reflect the Life Science Content Standards for grades K-4 and 5–8?
- 6. Does the curriculum prepare students to be scientifically literate citizens?

Journals composed by the students were used as a means of assessment. These were read weekly by the instructor. In addition, prior to the introduction of a new unit or topic, "students [were] asked to write what they already know about the topic in their journals. For example in the Plant Unit, students were asked to respond to the following prompt: 'What I remember about photosynthesis is...'" (Friedrichsen, 2001; p. 566). A class discussion was then initiated by students sharing their journal entry with the other members in their team. There were also times when students exchanged journals and gave feedback to each other.

#### The University of Northern Colorado

During the mid-1990s, Colorado State University, Metropolitan State College of Denver, and the University of Northern Colorado collaborated with three two-year community colleges in Colorado to design courses for which inquiry-based teaching standards were modeled (Jones, 1997). Their goal was to "improve the education" (Jones, 1997; p. 787) of pre-service teachers of science and mathematics. Several chemistry courses were designed to "help students connect desired teaching methods with chemistry teaching" (Jones, 1997; p. 787). One such course was "Seminar in the Teaching of Chemistry" at the University of Northern Colorado. All chemistry and physical science undergraduates with a teaching emphasis were required to enroll in this course. Designers "wanted to ensure that students...would be prepared to set up a chemistry classroom and laboratory, and implement...inquiry-based strategies" (Jones, 1997; p. 787). The purpose was to create an environment for which the majority of the activities performed in the course would be the same sorts of activities "that a teacher might perform (such as presenting a demonstration), rather than 'school activities' (such as writing an essay about demonstrations)" (Jones, 1997; p. 787). Every assignment involved students in developing skills that would later be used in the classroom environment. The problems presented in the course were "not only simple ones that illustrate one idea or principle, but [were] often complex ones that students must solve by pulling together ideas from several sources" (Jones, 1997; p. 787).

There were at least five ways that this course differed from a traditional chemistry course. First, the course did not focus on lectures, but rather on activities, discussion, and investigations. Second, the topics presented in the course were determined through a 1994 survey of practicing teachers (Jones, 1997; p. 787):

The teachers indicated that they felt their preparation to be deficient in the areas of safety and the use of technology, and that one of the most difficult aspects of beginning to teach was setting up a laboratory program. Thus, we decided to focus on safety, laboratory work and management, and the use of technology, as well as on teaching strategies for active learning.

Third, students visited "exemplary local chemistry classrooms to find out how expert teachers...integrate student activities into classes" (Jones, 1997; p. 788). Fourth, students were involved "singly or in pairs in the teaching of each class. For example, the class not only performed an inquiry lab, but two students introduced them to it and led the analysis of its learning potential" (Jones, 1997; p. 788). Fifth, no quizzes or examinations were given. Assessments involved "the presentation of a demonstration, a hands-on activity, and an interactive concept-teaching lesson which [were] evaluated by both peers and instructor. Written assignments [were] shared among students to use later in their own teaching" (Jones, 1997; p. 788). The students developed the rubrics "for all performance-based assessments" (Jones, 1997; p. 788).

#### Pennsylvania State University

During the mid 1990s, pre-service elementary teachers who enrolled in a typical introductory science course at Pennsylvania State University were exposed to a "large lecture format that was only sometimes coupled with a laboratory or recitation section. These courses rarely attempt to combine the content that students must study with the context of their prospective careers..." (McLoughlin, 1999; p. 71). In response to this, six members of an inter-departmental instructional team began to design an inquiry-based experimental course that would teach concepts related to several disciplines of science.

The team included professors of molecular biology, chemistry, physics, and science education; and graduate students in chemistry and science education. A draft copy of the National Science Education Standards that was available in 1994 was used as a guide for determining the appropriate science content that was to be presented in the course. Some of topics addressed included "developing understandings of the characteristics of organisms and their environments, the properties of earth materials, the forms and uses of energy, and the abilities necessary to do scientific inquiry" (McLoughlin, 1999; p. 72). This experimental course was offered during the summer of 1995. The course consisted of three-hour sessions that were held four days a week for four weeks. All instructors on the team participated in the teaching of the course (McLoughlin, 1999; p. 72):

Each instructor attempted to integrate connections to all of the sciences within each developing lesson. It was planned that only two instructors would need to meet with the class on any given day, the content instructor primarily in charge of the day's lesson and one of the science education instructors.

As the course was experimental, means for assessing its effectiveness were developed that were interpretative in nature, and included "an hour-long semi-structured interview with...five student participants, brief open-ended student and instructor questionnaires, documents from participants' coursework, and fieldnotes taken during class sessions..." (McLoughlin, 1999; p. 73). At least four impacts of the course were observed when these data were analyzed. First, pre-service teachers "felt that they had made gains in both content knowledge and pedagogical content knowledge due to the course" (McLoughlin, 1999; p. 84). Second, pre-service teachers "continually noted their appreciation that the science content they learned was made meaningful to them through practical applications of content, both in terms of pedagogy and in terms of seeing science applied in real life situations" (McLoughlin, 1999; p. 84). Third, the students "talked in emotional terms about feeling personal validation in themselves as learners and about seeing themselves as persons able to research, do, and learn science. For most of

the prospective teachers, this was a feeling over which they had had little or not previous ownership" (McLoughlin, 1999; p. 84). Fourth, pre-service teachers "did feel more confident in their abilities to be teachers of science, motivate children, and use activities successfully in their future classrooms" (McLoughlin, 1999; p. 84).

At least one problem arose during the instruction of the course. Significant tensions developed between the instructors and the students over different expectations (McLoughlin, 1999; p. 86):

While the course was designed to integrate the learning of science content with the learning of science pedagogy, the prospective teachers seemed to expect the course to be almost entirely a methods course, while the instructors seemed to expect it to deal much more exclusively with college-level content understandings. As the clash in perspectives emerged, frustration with the course became evident. A good amount of this frustration was defused by addressing the issue directly during class, but some residual frustration about the miscommunication seemed to remain for both parties.

### Western Michigan University

It was during the mid to late 1990s that science educators within the Mallinson Institute for Science Education, then known as the Department of Science Studies, at Western Michigan University began to argue that many graduating elementary education majors were not being equipped with sufficiently adequate knowledge and skills to achieve the objectives of the Michigan Essential Goals and Objectives for Science Education. It was believed that "student experiences in the university classroom discouraged creativity and intelligent thought" (Mallinson Institute for Science Education, 2004; p. 1) because these courses were designed to direct students to "rote learned facts and verify them through 'canned' experiments. Such courses blocked most of the 'feel' of scientific inquiry and the ability to question the concepts and why they are important" (Mallinson Institute for Science Education, 2004; p. 1). Traditional science

concepts, or else!" (Mallinson Institute for Science Education, 2004; p. 1). This resulted in students becoming "either baffled, discouraged, or angered by their scientific experiences" (Mallinson Institute for Science Education, 2004; p. 1). In response to this, it was decided to design science courses that would emphasize the fundamental concepts of the sciences by providing inquiry-based laboratory experiences (Mallinson Institute for Science Education, 2004; p. 1):

The course activities would be broken into learning modules where students would design and implement their own experiments, prove their own conclusions, report on the results, and identify the types of natural environments to which the experiments apply.

The designing of activities for earth science initially occurred through the collaborative cross-departmental efforts of a team that included a professor in geography, a professor in geology, and a graduate student in science studies. The first course of "Earth Science for Elementary Teachers I" (Geography 1900) was taught during the Winter 1998 semester. The first course of "Earth Science for Elementary Teachers II" (Geosciences 2900) was taught during the Fall 2001 semester. These courses were designed as part of a three-year United States Department of Education grant that was awarded in 1995. The grant was "designed to fund the creation and implementation of a complete curriculum for elementary teachers" (Mallinson Institute for Science Education, 2004; p. 1) that included physics, biology, earth science, and chemistry. The philosophies that governed the creation of these courses were based on many of the same principles used to generate the inquiry-based standards within the National Science Education Standards, the National Geography Standards, and the Michigan Curriculum Framework.

All students who enrolled in "Earth Science for Elementary Teachers I" and "Earth Science for Elementary Teachers II" were expected to purchase a course pack that contained an overview of the lab activities. Each activity included a brief introduction to the topic, a few basic thought provoking introductory questions, and a series of

"Outcome" and "Reflection" questions designed to elicit inquiry and stimulate thought. The following instructions were included within the course packs to help guide students as they worked through each activity (Mallinson Institute for Science Education, 2004; p. 2):

Work through each activity and use the questions to help guide your thinking as you determine what is happening. Once you understand the processes involved you can begin to synthesize the ideas into a general statement which summarizes the principles and concepts. The next stage is to apply the information to explain new situations or data. An important part of this learning process is discussion. You and other students will exchange ideas and suggestions, with the intent of gaining understanding of earth science.

Several course goals were added to the Geography 1900 course pack beginning with the Fall 2005 semester. While these goals were not expressly stated within the course pack possessed by students at the time this study was conducted (August 2004 through April 2005), the goals are worth noting because they reflect the goals that have governed both the Geography 1900 and Geosciences 2900 courses throughout the entirety of their histories (Mallinson Institute for Science Education, 2006; p. 5):

- 1. Understand why it is important for children to learn earth science;
- 2. Learn key concepts of earth science through the process of inquiry;
- 3. Be able to reflect upon the nature of practice of earth science as a process rather than a body of disconnected facts to be memorized;
- 4. Be better able to make decisions concerning what concepts in earth science are the most important for children to learn; and,
- 5. Reflect upon how they themselves learn earth science and the implications of these reflections for how it should be taught.

# Inquiry and Content Achievement

No research comparing the effect of a pedagogical approach, that of inquiry-based instruction versus traditional, on content achievement was conducted for the courses offered at the University of Maryland, the University of Northern Colorado, the University of Nebraska-Lincoln, Pennsylvania State University, and Western Michigan University. The impacts of these courses have only been assessed through qualitative interpretations of data obtained from one or more of the following sources: student journals, questionnaires, course evaluations, field notes, course work, essay examinations, and transcripts of personal interviews. Wilden sees this as controversial and suggests that if "colleges and universities are going to be convinced that designing such courses, which require money and faculty resources to develop and teach, rather than keeping what is currently being taught, evidence must be shown that the students who participate in them are learning more than a positive attitude" (Wilden, 2002; p. 3). Wilden's concern is directly addressed through the current dissertation project being reported here.

Studies have been conducted to compare the effects of pedagogical approach (inquiry-based versus traditional) on content achievement for courses other than those designed for pre-service teachers. While the courses analyzed by these studies were not designed with the exact same standards that were used to design the courses described above, it is useful to examine the designs of these studies because they provide a framework for how much of the research was designed for this dissertation project (see the next chapter on "Research Design").

### Taiwanese Secondary Schools

Mao & Chang (1998) performed a study comparing the effect of inquiry-oriented instruction with that of traditional instruction on content achievement toward astronomy and meteorology concepts. The participants were 557 9<sup>th</sup> grade students enrolled in 14 earth science classes in four secondary schools in northern Taiwan. Half of the classes (284 students) were randomly assigned to an inquiry-based approach, while the other half (273 students) were randomly assigned to a traditional lecture approach. An instrument known as The Earth Science Achievement Test "was constructed and designed to measure Earth science content achievement and to assess knowledge, comprehensive, and

application level objectives of the cognitive domain" (Mao & Chang, 1998; p. 95). The chemistry portion of the posttest contained twenty-six questions, with thirteen of these questions comprising the pretest. The meteorology portion of the posttest contained twenty-four questions, with eight questions being included on the pretest. Using the Cronbach alpha method, the reliability of the chemistry posttest was estimated as being 0.82 and the reliability of the meteorology posttest was estimated as being 0.78.

Content validity of the instrument was verified by a committee of experts that included four professors from the Department of Earth Sciences from the National Taiwan Normal University. The experts "checked the correspondence between the treatment and test item contents, and determined that the nature of the test question was strongly related to the important concepts introduced in the instruction" (Mao & Chang, 1998; p. 95). Each member of the content validity committee was asked to classify the instrument items into one of the following categories from Bloom's Taxonomy (Bloom, 1956): knowledge, comprehension, and application. They each did so "with high agreement" (Mao & Chang, 1998; p. 95). For the chemistry posttest, five questions were classified as knowledge, sixteen questions were classified as comprehension, and five questions were classified as application. For the meteorology test, five questions were classified as knowledge, eleven questions were classified as comprehension, and eight questions were classified as application.

The Earth Science Achievement Tests were "administered to all of the students at the beginning of the treatment as the pretests and were given again as the posttests at the conclusion of each respective instruction period" (Mao & Chang, 1998; p. 97). The tests were statistically analyzed in the following way (Mao & Chang, 1998; p. 97):

The data were analyzed by employing analysis of covariance (ANCOVA) on posttest scores with the pretest as the covariant to determine any significant differences between the experimental group and the control group. ANCOVA was also conducted at the factual, comprehensive, and the [application] levels of the posttest measures to determine if there were

significant differences between the two groups at these levels of understanding. The assumptions of ANCOVA were first checked to insure that they were met in the analysis of covariance for these studies.

The findings of this analysis indicate that, for both astronomy and meteorology content, "subjects taught using the inquiry-oriented instructional method scored significantly higher than those taught using the traditional method" (Mao & Chang, 1998; p. 97). Statistically significant higher scores were also observed for astronomy content at the knowledge and comprehension levels, and for meteorology content at the comprehension and application levels. No significant differences at the knowledge level were observed for the meteorology content. The authors suggest that this was because rote memorization aided the performance of the traditional lecture group "at that level" (Mao & Chang, 1998; p. 99). No significant differences at the application level were observed for the astronomy test. The authors suggest that this was because "the nature of the [application] test items for Astronomy was difficult for students or that the number of [application] items (only five items at this level) was not sufficient to obtain a statistical distinction between the experimental and control groups" (Mao & Chang, 1998; p. 99). Nevertheless, the authors concluded that "these two studies generate evidence to support the notion that the inquiry-oriented approach is more effective in enhancing *learning of Earth Science concepts* than is a more traditional teaching method" (Mao & Chang, 1998; p. 98-99).

### The University of New Mexico

A study was performed at the University of New Mexico to examine the "effects of laboratory instruction method on a spectro-photometry achievement test...using an analysis of covariance" (Jackman, *et. al.* 1987; p. 794). Eighteen of the nineteen laboratory sections from a general laboratory course were randomly assigned to one of following three instructional methods: traditional, learning cycle, and computer simulation.

A total of 95 students were taught by the traditional approach that made use of "teacher-structured laboratory exercises or experiments" (Jackman, *et. al.*, 1987; p. 794). Another 98 students were taught by the learning cycle, a form of guided inquiry that made use of "exploration, invention, and discovery (applications)" (Jackman, *et. al.*, 1987; p. 794). The remaining 95 students were taught by the simulation approach that made use of computers "in at least three general ways: computer assisted instruction (CAI), computer-managed instruction (CMI), and computer-assisted learning (CAL)" (Jackman, *et. al.*, 1987; p. 794). The authors refer to five articles that discuss these teaching applications in more detail (Moore & Collins, 1979; Moore, *et al.*, 1979, Moore, *et. al.*, 1980; Moore & Moore, 1984; Moore, *et. al.*, 1984).

All participants were asked to answer several background questions related to class, program of study, grade point average, age, and gender. Approximately 51% of the participants were freshmen, 31% sophomores, 11% juniors, and 5% seniors. The remaining participants did not report their class. Approximately 51% of the participants were engineering majors, 25% were physical science majors, and 15% were health sciences majors. Business, education, English, and psychology majors made up 3.1% of the participants. The remaining participants were either undecided or declined to report their programs of study. The mean grade point average for all participants was 3.0, with 1.6 being the lowest reported and 4.0 being the highest reported. The median age of the participants was 19.5 years, with 17 being the youngest and 42 being the oldest reported age. Approximately 62% of the participants were male, while 36% were female. Approximately 2% of the subjects did not report their gender.

The dependent variable was spectrophotometry achievement, and it was measured by a test that was described as follows (Jackman, *et. al.*, 1987; p. 795):

Although spectrophotometry is a large and diverse area within chemistry, at the freshman level, only some of the more elementary concepts and techniques are covered, and the achievement test was written to include only those aspects relevant to a freshman or introductory general science course. More important, the test items were written to include only those aspects of spectrophotometry that were included in the instructional methods that students were exposed to and were expected to learn. The two forms used as the pretest and posttest in this study contained 20 items each...

A pilot study was conducted on the pretest/posttest, during which the reliability of

the pretest was estimated as being 0.78 and the reliability of the posttest was estimated as

being 0.79. Both tests "were nearly equal in difficulty: the mean raw score for [the

pretest] was 11.56 and for [the posttest] was 11.32" (Jackman, et. al., 1987; p. 795).

The test was completed by students during the main study in the following

manner (Jackman, et. al., 1987; p. 795):

The traditional and learning cycle methods (but not the simulation) contained a prelaboratory exercise that was given to students one week prior to the remainder of the laboratory exercise. For all subjects, the pretest was administered at the conclusion of the immediately preceding laboratory period (before students were given the prelaboratory exercise). At the conclusion of the spectrophotometry laboratory, subjects from all three instructional methods were given the posttest. The posttest was given immediately at the end of the laboratory period. The pretest and posttest were computer scored.

The analysis of covariance revealed "a statistical significant difference among the three instructional methods" (Jackman, *et. al.*, 1987; p. 795). The simulation approach had a significantly greater effect on achievement than either the traditional or the learning cycle approaches. The learning cycle approach did not have a significantly greater effect on achievement than the traditional approach.

## CHAPTER III

### **RESEARCH DESIGN**

### The Sample

A *quasi experimental control group design* involves the administration of a pretest and a posttest to an experimental group and a control group where neither group has "pre-experimental sampling equivalence" (Campbell & Stanley, 1963; p. 47). In other words, groups must be "naturally assembled collectives such as classrooms" (Campbell & Stanley, 1963; p. 47) that permit a degree of similarity, but "not so similar that one can dispense with the pretest" (Campbell & Stanley, 1963; p. 47). The assignment of subjects to either the control or experimental group should be "random and under the experimenter's control" (Campbell & Stanley, 1963; p. 47). While the design of this research project included most of these characteristics, the selection of the subjects was neither random nor under the control of the researcher.

The experimental treatment sample consisted of pre-service elementary teachers enrolled in "Earth Science for Elementary Teachers I" offered as Geography 1900 and "Earth Science for Elementary Teachers II" offered as Geosciences 2900. These were the inquiry-based courses designed by the Mallinson Institute for Science Education to meet the goals of the Michigan Curriculum Framework (Michigan State Board of Education, 1991, 2000, 2004). At the time this study was performed, atmospheric science content was divided between the two courses. The first half of the meteorology unit was taught in Geography 1900, while the second half was taught in Geosciences 2900. Each course section met twice per week in two and a half hour blocks. The enrollment did not exceed 24 students. Six tables, each with a computer connected to the Internet, were set up for four students each. Classroom activities were conducted using coursepacks specifically designed for the inquiry-based courses. Several textbooks were available on a bookshelf in one corner of the classroom. Materials needed to conduct the activities were placed on a counter prior to the start of class. Students were responsible for collecting their own materials.

The traditional treatment sample included pre-service elementary teachers and general education students enrolled in the lecture and laboratory-based "Physical Geography" course offered as Geography 1050. The lecture sessions met in a large hall three times per week in 50 minute blocks. The meteorology unit was conducted during the first half of the semester. Students were required to purchase the textbook *Elemental Geosystems* (Christopherson, 2003) and to read the chapters assigned for each lecture session. Several laboratory sections taught by graduate student assistants were offered at various times of the week. Each student was required to register for and attend one of these laboratory sections, each of which met for a one hour and fifty minute block. The enrollment of each laboratory section did not exceed 25 students. There were three large tables in the laboratory classroom, each with several computers connected to the Internet. Activities were conducted using a laboratory activities were written on the whiteboard in the front of the classroom by the graduate student assistants. Students worked individually or with up to three other students.

The control sample included pre-service elementary teachers and general education students enrolled in Geography 1020, a "World Geography" course for which no atmospheric content was presented. These students were used as a means for detecting the degree to which growth could be achieved as a result of the pretest or content encountered in other situations without the benefit of an earth science course for which atmospheric science content is presented. Events unrelated to class have the potential to provide students with insights that lead to a better posttest performance.

Subjects naturally get "older and wiser" (Huitema, 2002). In other words, it is possible for a student to be exposed to a concept asked on the test *after* completing the pretest but *before* completing the posttest. An example would be a participant receiving insights into a test question after watching the Weather Channel.

# Data Collection and Sampling Technique

Students were tested at the beginning of each course's meteorology unit (the pretest) and again at the end of each course's meteorology unit (the posttest) regarding their understanding of atmospheric science concepts emphasized by the Michigan Curriculum Framework. The design was a repeated measures in which the questions on the posttest were identical to the questions on the pretest.

Students from four Geography 1900 class sections were selected for participation in the research. Two of these class sections, one during the Fall 2004 semester and the other during the Spring 2005 semester, were taught by an instructor who will hereafter be identified as "Instructor 1." These two sections provided 20 students in the Fall 2004 class section and 21 students in the Spring 2005 class section. Students had to agree to participate in the study. The remaining two class sections of Geography 1900 were taught during the Spring 2005 semester by an instructor who will hereafter be identified as "Instructor 2." Twenty students from each of the class sections elected to participate in the study. There were therefore 81 participants enrolled in Geography 1900 class sections; 75 were female and 6 were male. All but two of the participants reported that they were between the ages of 18 and 25. One participant was 27 years old, and one chose not to state an age.

One Geosciences 2900 class section was available for participation. This class section was taught by "Instructor 2." More sections would have been preferred, but no additional sections were available. There were 19 students in the Geosciences 2900 class

section who agreed to participate; 18 were female and one was male. All but one of the participants were between the ages of 20 and 23. One participant was 34 years old.

Two Geography 1050 class sections were selected for participation, one during the Fall 2004 semester and the other during the Spring 2005 semester. Both of these class sections were taught by the same instructor. Sixteen participants were selected from one of the laboratory sections of the Fall 2004 class section. Fifty-two participants were selected from all five laboratory sections of the Spring 2005 class section. There were therefore 68 participants enrolled in Geography 1050 class sections; 36 were female and 32 were male. All but three of the participants reported that they were between the ages of 18 and 23. One participant was 37 years old, and two chose not to state an age.

One Geography 1020 course was selected for participation. This course was taught during the Fall 2004 semester. There were 14 students who elected to participate; 10 were male and 4 were female. All but one of the participants were between the ages of 18 and 23. One participant was 26 years old.

A total of 182 students participated in this study. Each student from each section within the four courses received the pretest/posttest. It should be noted that there were students who chose not to participate in the study. Students who chose not to participate remained in the classroom while the pretest/posttest were given, but were required to remain silent until all participating students completed the tests.

There was a practical reason for focusing the study on atmospheric science content rather than broadening it to cover all major areas of earth science. Adequately testing students' understandings of other areas of earth science (such as hydrology and geology) would have resulted in a pretest/posttest that was much too involved to be completed within a reasonable amount of time. Focusing the test on a single aspect of earth science, namely atmospheric science, allowed an adequate number of questions to be asked without the pretest/posttest becoming too long to be accommodated within the instructional program for each class.

There was also a practical reason for giving the pretest/posttest to Geography 1050 students during lab sessions rather than lecture sessions. Reservations about using lecture time were expressed by the instructor of Geography 1050 because it would be necessary to administer the tests in a large lecture hall. The laboratory was seen as a much more controlled setting for the administration of the pretest/posttest.

The researcher has worked closely with the instructors who taught the courses that were used in this study. All of them expressed a willingness to allow class or laboratory time to be used for the completion of the pretest/posttest. The researcher did not participate in any instruction, but did administer the pre- and posttest. This allowed the data collection stage to proceed smoothly.

All non-education students enrolled in Geography 1050 were given the opportunity to participate. This allowed additional information to be elicited for research. Moreover, allowing non-education students to participate eased the data collection for this course. A time separate from the lab sessions would have been required if the research were to limit participation to one segment of the class. Motivating students to attend an extra session may have proven to be difficult, and the issue of providing a reward for participation would have become complicated. A self-administered questionnaire would have resolved this problem, but this was not a practical solution because students would be able to formulate responses by reading a book or browsing the Internet. The participation of the students in classes as described earlier permitted the researcher to maintain control of the content treatments.

### The Pretest/Posttest

Each participant individually completed his or her own test. The individual student was therefore both the unit of analysis and the unit of observation. The use of books, notes, and discussions with other participants was prohibited. Anyone caught

violating this rule would have been immediately removed from the study, although this never occurred. The test was administered to those who consented. The researcher prepared an introduction that was distributed and read to each class prior to the administration of the test. The introduction provided basic instructions as to how the test was to be completed; it explained that research was being conducted about the teaching of earth science; and it emphasized that participation was voluntary. Any additional questions that students had were answered. Students were asked to sign an "informed consent" document before they were allowed to complete the tests. The introduction that was distributed and read to all classes is in Appendix C. The informed consent document is in Appendix D.

Instructors were asked to not give extra credit to those who completed the tests. A few problems may have been introduced into the study if one or two of the instructors had chosen to give extra credit, especially if students who did not receive extra credit were to discover that students in other classes did receive extra credit. It therefore was decided by the researcher to establish a policy of consistency so that the study was not biased by an external reward factor.

The test was designed to be completed within 20 minutes. Each student provided his or her full name. Students were informed that their names would eventually be removed from the test and replaced with random numbers. The research was designed so that no information that could match responses to a particular respondent would be revealed. A space was included for each student to identify his or her major program of study. This allowed the researcher to easily classify education students (the target population). Other categories of students were classified as well. The pretest contained an additional section that was designed to elicit general information about students' backgrounds, and could be completed within a few minutes. It contained questions related to various themes (such as study habits and computer skills) that were of research

interest, and was similar to what was given to Geography 1900 students at the beginning of every semester. The pretest cover page and background questions are in Appendix E.

The test consisted of 21 unique multiple-choice questions related to the K-8 Michigan benchmarks for the atmosphere and weather content standard of Strand V (Michigan State Board of Education, 2004).

Three questions each were asked about "Benchmark E.2: Describe seasonal changes in Michigan's weather," "Benchmark E.3: Explain appropriate safety precautions during severe weather," "Benchmark MS.2: Describe the composition and characteristics of the atmosphere," "Benchmark MS.3: Explain the behavior of water in the atmosphere," and "Benchmark MS.4: Describe health effects of polluted air."

No questions were asked about "Benchmark E.1: Describe weather conditions." Concepts addressed by this benchmark were extremely general, and the remaining benchmarks addressed these concepts to a greater depth. In order to avoid redundancy, it was decided not to formulate test questions about this benchmark.

Six questions were asked about "Benchmark MS.1: Explain patterns of changing weather and how they are measured." This benchmark addressed several weather concepts and phenomena, including air masses, fronts, lake-effect snow, sudden changes in temperature and atmospheric pressure, cloud formation, weather maps, satellite images, forecasting, and weather instruments. Three additional test questions were therefore formulated in order to better address the large range of concepts included within this benchmark.

Some questions were formulated to examine understanding about the *key concepts* (*vocabulary*)/*tools* dimension of the MI CliMB (Michigan State Board of Education, 2004), while other questions were formulated to examine understanding about the *real-world context* dimension of the MI CLiMB (Michigan State Board of Education, 2004). The knowledge, comprehension, and application levels of Bloom's Taxonomy (Bloom, *et. al.*, 1956) were used to judge items. Multiple choice questions formulated at the

knowledge and comprehension levels were used to examine the *key concepts* (*vocabulary*)/*tools* dimension, and multiple choice questions formulated at the application level were used to examine the *real-world context* dimension. Knowledge involves "those behaviors and test situations which emphasize remembering, either by recognition or recall, of ideas, material, or phenomena... In the learning situation the student is expected to store in his mind certain information, and the behavior expected later is the remembering of this information" (Bloom, *et. al.*, 1956; p. 62). Comprehension such that the individual knows what is being communicated and can make use of the material or idea being communicated without necessarily relating it to other material or seeing its fullest implications" (Bloom, *et. al.*, 1956; p. 204). Application involves "the use of abstractions in particular and concrete situations. The abstractions may be in the form of general ideas, rules of procedures, or generalized methods. The abstractions may also be technical principles, ideas, and theories which must be remembered and applied" (Bloom, *et. al.*, 1956; p. 205).

The pretest/posttest is in Appendix F. Students were given several diagrams and maps that were used with specific test questions. Some of these diagrams were taken from Barron's *Let's Review: Earth Science—The Physical Setting* (Denecke, 2003). This material is copyrighted. The publisher of the book was contacted, and the appropriate written legal permission for use of the material was granted. This permission did not include the right to reproduce the diagrams in this dissertation. These diagrams are therefore not included with the pretest/posttest in Appendix F.

#### Instrument Field Review

In the context of this study, *validity* answers the critical question of whether the pretest/posttest actually measures atmospheric science content. This question was

addressed through a panel of experts. Several earth science instructors were asked to analyze the test in the following areas:

- 1. *Accuracy of the science content*. Experts were asked to examine the wording of the questions, and the correctness of the answers to the questions.
- 2. Consistency of the test questions with the Michigan Curriculum Framework benchmarks. Experts were asked to read the Michigan Curriculum Framework's "Benchmarks and Clarifications for Elementary School" and "Benchmarks and Clarifications for Middle School," and to evaluate whether the questions in the test truly reflected these benchmark standards.
- 3. Accuracy of the classification of questions. Experts were asked to evaluate whether particular test questions were knowledge, comprehension, or application in nature.

Those with the following qualifications were asked to participate

- 1. An "expert" had at least five years of teaching experience.
- 2. An "expert" possessed a doctoral degree, or was enrolled in a doctoral program at the time of the study.
- 3. An "expert" had his or her field of concentration within the earth sciences.

This portion of the study was conducted between July 22, 2004 and August 6,

2004. Twelve experts who met the above criteria were asked to participate. Three agreed to participate: 1 high school earth science instructor, 1 emeritus university earth science instructor, and 1 doctoral student enrolled in a science education program.

Minor modifications were made to the test between August 7, 2004 and August

10, 2004. These changes were based on suggestions made by the three-member content validity committee. Overall, the content of the test was validated by the experts.

## Field Test

The pretest/posttest was field tested three times. Seven elementary education students enrolled in an inquiry-based chemistry course at Western Michigan University completed the test on August 11, 2004. Two elementary education students enrolled in

an inquiry-based earth science course completed the test on August 30, 2004. Twentytwo students enrolled in a World Geography course completed the test on August 31, 2004. The 31 field test results were used to analyze the internal consistency, or reliability of the instrument.

In the context of this study, *reliability* is an estimate indicating whether the test consistently measures atmospheric science content within and among respondents. The help tool for of the SPSS<sup>®</sup> statistical software explains how this is accomplished through the split-half approach which splits the responses in each test administered "into two parts and examines the correlation between the two parts" (SPSS, 2003a). If there is perfect reliability, then the two halves will be perfectly correlated (r = 1). Lower values of r are indications of less than perfect correlation. The assumption is that subsequent applications of the instrument will demonstrate similar consistency of scores. This could occur at a later date or with a comparable sample of respondents. The theoretical assumption is that the test will not exhibit random variations in student performance due to the structure of the test or individual items.

Using the SPSS statistical software package (SPSS, 2003b), the reliability of the test was estimated as being 0.85 by the Spearman-Brown split-half coefficient and 0.84 by the Guttman split-half coefficient. This is similar to the reliability estimates observed for the tests used within the two studies (cited in the previous chapter) that provide much of the framework for the design of this study (Mao & Chang, 1998; Jackman, *et. al.*, 1987). In comparison with these research studies, it was judged that the internal consistency of the instrument used in this research was acceptable.

#### Analysis

The overall pretest and posttest scores were calculated for each student in terms of the percentage of correct responses. These scores were analyzed in several ways. First, a

one-way ANOVA was performed on all pretest scores to determine whether there were statistically significant differences in the initial knowledge, comprehension and application skills among class sections. Second, t-tests for paired samples were performed on the pre- to posttest difference scores (pretest scores subtracted from the posttest scores) for all class sections to test for statistically significant differences between pretest and posttest scores. Third, McNemar chi-square tests for matched pairs were performed for all 21 items of the pretest/posttest for all classes to determine which questions produced a statistically significant increase in the number of correct responses from pre- to posttest.

The data collected from education students enrolled in Geography 1050 were separated from the data collected from non-education students enrolled in that course. A t-test for paired samples was calculated for each class section for education and noneducation students to test for significant differences between pretest and posttest scores.

The test scores were compared with responses to the pretest background questions in order to determine whether test score differences were the effect of conditions other than classroom instructional approach. Responses to the background questions included with the pretest were coded numerically. Mean pretest and posttest scores were calculated for students at each response level within each question, and statistical analyses were performed to test for significant differences across responses.

#### **Classroom Observations**

Classroom observations data were collected for one Geography 1050 lecture section, one Geography 1050 laboratory section, two Geography 1900 sections, and one Geosciences 2900 section. The researcher observed 11 Geography 1050 lecture sessions, 5 Geography 1050 lab sessions, 16 Geography 1900 class sessions (9 for one class section and 7 for another), and 7 Geosciences 2900 class sessions that were related to

atmospheric science content. Hand-written observations related to the behavior of both students and instructors were made and later word processed by the researcher. This was done in order to insure that Geography 1900 and Geosciences 2900 were indeed taught using an inquiry-based approach, and that Geography 1050 was indeed taught using a traditionally-based approach. A sample of these observations is in Appendix G.

For the purpose of inter-observer reliability, a second person was hired to observe and record simultaneous data for 3 Geography 1050 lecture sessions, 3 Geography 1050 laboratory sessions, 6 Geography 1900 class sessions (3 for each of the class sections for which observations were made), and 3 Geosciences 2900 class sessions. This second person was trained to observe and to make similar hand-written observations as the primary researcher. The primary observer and the second observer sat at opposite sides of the classroom in order to avoid influencing each others observations. These handwritten observations were later word processed by the researcher. A sample of the second person's observations is in Appendix H.

All classroom observations were later coded using a lesson observation system developed by the Science and Mathematics Program Improvement (SAMPI) faculty at Western Michigan University. This system is based on Michigan and national science education standards and has an orientation toward an inquiry approach to learning (Science and Mathematics Program Improvement, 2003c).

All instructors whose class sessions were observed, and one graduate student teaching assistant whose lab sessions were observed, were asked to sign an informed consent document. This informed consent document is in Appendix I.

### Interview Sessions

All students were asked to participate in an interview session. These sessions were conducted after the completion of the posttest. Those who indicated that they were

willing to be interviewed participated in this portion of the study. Interviewees were questioned about their knowledge, comprehension, and application skills with regard to the atmospheric science concepts for which they were tested. This was done under the assumption that anything discovered through an interview could provide clarifications to findings and conclusions reached through the analysis of the test scores. Interviews were conducted at various times to accommodate the schedules of the students. All interviews were recorded on audiotape and were later transcribed. The duration of each interview was at least 20 minutes and did not exceed 30 minutes. All interviews were conducted individually in a quiet classroom with the doors shut. No one except the interviewee and the researcher were allowed in the classroom while an interview was being conducted.

Interviews were analyzed qualitatively. The interview sessions were meant to clarify students' knowledge, comprehension, and application skills. No formal coding was used for the interviews. Rather, the researcher attempted to discern patterns in students' knowledge, comprehension, and application skills that could not be detected by the multiple choice pretest/posttest. Were there ideas that many students shared? Were there common misconceptions? Were their common conceptual attributes?

A sample transcribed interview session is in Appendix J.

## CHAPTER IV

### FINDINGS

### Pretest/Posttest

### **Overall Analysis**

*The Pretest Scores.* A one-way ANOVA was performed on all pretest scores to determine whether there were statistically significant differences among the mean pretest scores for the four Geography 1900 class sections, the two Geography 1050 class sections, the Geosciences 2900 class section, and the Geography 1020 class section. The p-value was 0.23, indicating that there were no statistically significant differences among the class sections at the 95% level of confidence. The initial level of knowledge, comprehension and application skills with regard to the test questions was therefore similar across class sections.

The highest mean pretest score (0.509) was attained by students enrolled in Geosciences 2900 (Table 1). This was expected given that 11 of these students already completed Geography 1900. However, the ANOVA analysis indicated that the mean pretest score for Geosciences 2900 was not significantly higher statistically than the mean pretest score for any of the remaining class sections. One reason that the mean pretest score was not significantly higher (as expected) could be because not *all* of the students in Geosciences 2900 completed Geography 1900. Even though Geography 1900 was designed to be a prerequisite for Geosciences 2900, students who had not completed Geography 1900 were allowed to enroll in Geosciences 2900. All students who completed the pretest in Geosciences 2900 were asked whether they had completed Geography 1900. An independent sample t-test was performed to determine whether

#### Table 1

Class	Approach	n	Pretest	Posttest	Difference	p-value
Geog 1900a (Fall 2004)	Inquiry	20	0.431	0.448	0.017	0.52
Geog 1900b (Spring 2005)	Inquiry	21	0.442	0.426	-0.016	0.59
Geog 1900c (Spring 2005)	Inquiry	20	0.388	0.438	0.050	0.17
Geog 1900d (Spring 2005)	Inquiry	20	0.417	0.476	0.060	0.12
Geog 1050a (Fall 2004)	Traditional	16	0.443	0.518	0.075	0.02*
Geog 1050b (Spring 2005)	Traditional	52	0.457	0.514	0.057	0.00**
Geos 2900 (Spring 2005)	Inquiry	19	0.509	0.577	0.068	0.06
Geog 1020 (Fall 2004)	Control	14	0.493	0.531	0.037	0.07

Paired Sample t-tests for the Pretest/Posttest for Each Class Session

\*Significant at the 95% level of confidence

\*\*Significant at the 99% level of confidence

there was a statistically significant difference in pretest scores between those Geosciences 2900 students who had completed Geography 1900 (n = 11) and those who had not (n = 8). The students who had completed Geography 1900 correctly answered an average of 12 of the 21 pretest items, while those who had not taken Geography 1900 correctly answered an average of 9 questions. The p-value (0.06) indicated that this was not statistically significant at the 95% level of confidence. It may be surmised that the average pretest score for students enrolled in Geosciences 2900 was higher due to the knowledge, comprehension, and application skills gained by the majority of students who

had successfully completed Geography 1900, but this is not supported by statistical evidence.

*The Difference Scores.* Paired sample t-tests were performed on the pretest/posttests for all class sections. The average pretest, posttest, and pre- to posttest difference scores, as well as the p-values, for each class section are in Table 1.

The pre- to posttest differences in mean scores for all four Geography 1900 class sections were not statistically significant at the 95% level of confidence (p-values = 0.52, 0.59, 0.17, and 0.12). The pre- to posttest difference in mean scores for the Geosciences 2900 class section was not statistically significant at the 95% level of confidence (p-value = 0.06). It appears that little change took place in the inquiry-based class sections. It is even surprising to note that the average posttest score was actually lower than the average pretest score for one of the Geography 1900 class sections (Table 1).

The pre- to posttest differences in mean scores for Geography 1050a was statistically significant at the 95% level of confidence (p-value = 0.02). The pre- to posttest difference in mean scores for Geography 1050b was statistically significant at the 99% level of confidence (p-value = 0.00). It appears that these sections were more effective for teaching atmospheric science content according to the standards established by the Michigan Curriculum Framework for K-8 than were the inquiry-based sections.

The pre-to posttest difference in mean scores for the Geography 1020 class section was not statistically significant at the 95% level of confidence (p-value = 0.06). This was expected, given that the Geography 1020 section was the "control" group for which students were not presented atmospheric science content in the planned instruction.

#### Item Analysis

To determine which questions had a statistically significant difference in the number of correct responses from pre- to posttest, McNemar chi-square tests for matched

pairs were performed for the 21 test items for each class section. Glass and Hopkins (1996; p. 339) provide the following example of how a McNemar test is conducted:

Suppose a group of voters indicates whether they intend to vote for or against a certain candidate, and after hearing a debate, the same group responds again to the same question. The research question of interest here is whether there has been a significant change in the proportion of voters who favor the candidate. The  $\chi^2$  test of association for the 2 x 2 contingency table...would evaluate...whether there is a relationship between voter preference before and after the debate. In this research design calling for paired observations, we want to know if there has been a significant shift toward or away from the candidate...

As is the case with the present example, the most frequent application of McNemar's test for correlated proportions is to research designs in which the two sets of observations are from the same group of persons observed at two different points of time.

The following table illustrates how the  $2 \ge 2$  contingency table is constructed within the context of the present study:

	Pr I	Pr C
Po C	n <sub>11</sub>	n <sub>12</sub>
Po I	n <sub>21</sub>	n <sub>22</sub>

In this table, "Pr" represents the pretest, "Po" represents the posttest, "C" represents a correct response, and "I" represents an incorrect response. The four resulting cells are therefore defined as follows: the number of subjects who answered correctly on the posttest but incorrectly on the pretest  $(n_{11})$ , the number of subjects who answered correctly on both the pretest and the posttest  $(n_{12})$ , the number of subjects who answered incorrectly on both the pretest and the posttest  $(n_{21})$ , and the number of subjects who answered answered incorrectly on the posttest but correctly on the pretest  $(n_{22})$ .

The equation used to calculate the observed value is as follows:

$$\chi^2 = \left[ \left( n_{22} - n_{11} \right)^2 \right] / \left( n_{22} + n_{11} \right)$$

The observed value is compared to the critical value for the desired level of statistical significance.

As an example, the following contingency table presents the results from the Geosciences 2900 class section for Question 12 of the pretest/posttest ("If the low pressure center located between Denver and El Paso were to move northeast toward Chicago, what weather conditions would likely occur along the southern border of Michigan?"):

	Pr I	Pr C
Po C	8	3
Po I	8	0

In this example, 8 subjects answered correctly on the posttest but incorrectly on the pretest  $(n_{11})$ , 3 subjects answered correctly on both the pretest and the posttest  $(n_{12})$ , 8 subjects answered incorrectly on both the pretest and the posttest  $(n_{21})$ , and none of the subjects answered incorrectly on the posttest but correctly on the pretest  $(n_{22})$ . The observed value was calculated as follows:

$$\chi^2 = \left[ (0-8)^2 \right] / (0+8) = 8$$

Using a table from the appendix of a typical statistics textbook, the critical value for a 2 x 2 chi-square test was determined to be 3.84 at the 95% level of confidence, and 6.63 at the 99% level of confidence (Howell, 2002, p. 736). Since the observed value of 8 was greater than 3.84 and 6.63, there was a statistically significant pre- to posttest shift in performance at both the 95% and 99% levels of confidence.

McNemar chi-square tests for matched pairs were performed for all 21 test items for the four Geography 1900 class sections, the two Geography 1050 class sections, the
Geosciences 2900 class section, and the Geography 1020 class section. The observed values obtained from these tests are in Tables 2 and 3.

The Geography 1900 Class Sections. A statistically significant difference in the number of correct responses was made by students enrolled in Geography 1900a for question 14 ("What happens to the air temperature and atmospheric pressure as elevation increases?"), by students enrolled in Geography 1900b for questions 6 ("What is the primary reason for seasonal variations on Earth?") and 13 ("What are the two most abundant gases in the Earth's atmosphere?"), by students enrolled in Geography 1900c for question 17 ("What natural process is occurring at C?"), and by students enrolled in Geography 1900d for questions 14 ("What happens to the air temperature and atmospheric pressure as elevation increases?") and 19 ("What name is given to solid particles or liquid droplets that are small enough to be suspended in the air?") (Table 2). Question 6 referenced "Benchmark E.2: Describe seasonal changes in Michigan's weather." Questions 13 and 14 referenced "Benchmark MS.2: Describe the composition and characteristics of the atmosphere." Question 17 referenced "Benchmark MS.3: Explain the behavior of water in the atmosphere." A diagram of the water cycle was given for question 17. Question 19 referenced "Benchmark MS.4: Describe health effects of polluted air." Using Bloom's Taxonomy, questions 13 and 19 were categorized as knowledge and questions 6, 14, and 17 were categorized as comprehension. There were no application questions for which a significant difference in the number of correct responses was observed.

There was one question for which students enrolled in Geography 1900a made a statistically significant difference in the number of incorrect responses. This was observed for question 17 ("What natural process is occurring at C?") (Table 2).. This question referenced "Benchmark MS.3: Explain the behavior of water in the atmosphere" and was categorized as comprehension. A diagram of the water cycle was given with this question. The correct response was "Condensation is taking place within the cloud." Ten

Test Item	Benchmark Referenced	Item Category	Geog 1900a	Geog 1900b	Geog 1900c	Geog 1900d
1	MS.1	Knowledge	0.67	3.00	1.00	1.00
2	MS.1	Comprehension	0.14	3.57	0.11	1.80
3	MS.1	Application	3.77	1.00	1.29	0.00
4	E.2	Knowledge	2.00	0.20	0.00	1.00
5	E.2	Application	1.29	0.14	2.78	0.67
6	E.2	Comprehension	1.00	6.00*	0.00	2.67
7	E.3	Knowledge	0.33	5.00+	2.00	3.00
8	E.3	Comprehension	0.00	0.33	0.20	1.00
9	E.3	Application	0.33	0.33	3.00	0.67
10	MS.1	Knowledge	1.80	0.20	0.33	0.00
11	MS.1	Comprehension	3.00	$4.00^{+}$	4.46+	2.00
12	MS.1	Application	0.00	1.80	0.20	3.57
13	MS.2	Knowledge	2.78	6.40*	3.58	1.00
14	MS.2	Comprehension	7.00**	0.40	0.33	4.50*
15	MS.2	Application	2.00	0.00	0.14	2.67
16	MS.3	Knowledge	2.67	0.67	1.80	0.20
17	MS.3	Comprehension	5.44+	0.00	5.44*	2.00
18	MS.3	Application	0.11	1.00	2.00	1.29
19	MS.4	Knowledge	0.82	2.78	2.00	4.50*
20	MS.4	Comprehension	0.67	0.00	0.20	0.50
21	MS.4	Application	3.00	2.00	2.67	0.67

#### McNemar Chi-Square Tests for the 21 Pretest/Posttest Items for Each Geography 1900 Class Section (Observed Values)

\*Significant increase in the number of correct responses at the 95% level (critical value = 3.84, df =1).

\*\*Significant increase in the number of correct responses at the 95% level (critical value = 6.63, df =1).

\*Significant decrease in the number of correct responses at the 95% level (critical value = 3.84, df = 1).

Test Item	Benchmark Referenced	Item Category	Geog 1050a	Geog 1050b	Geos 2900	Geog 1020
1	MS.1	Knowledge	0.40	4.26*	2.67	2.00
2	MS.1	Comprehension	1.80	0.11	0.00	1.00
3	MS.1	Application	0.14	0.18	1.00	0.20
4	E.2	Knowledge	1.29	0.33	0.67	undefined
5	E.2	Application	1.80	0.22	1.80	1.00
6	E.2	Comprehension	3.57	2.25	0.20	4.00*
7	E.3	Knowledge	1.00	4.50*	2.00	undefined
8	E.3	Comprehension	1.00	5.40*	1.00	1.00
9	E.3	Application	1.00	0.29	0.50	0.00
10	MS.1	Knowledge	5.33*	9.84*	2.00	0.33
11	MS.1	Comprehension	1.00	5.56+	1.92	1.80
12	MS.1	Application	0.33	0.08	8.00*	undefined
13	MS.2	Knowledge	4.00*	7.14*	0.33	0.67
14	MS.2	Comprehension	0.33	0.40	$4.00^{+}$	2.00
15	MS.2	Application	0.14	0.69	0.20	0.33
16	MS.3	Knowledge	1.00	0.47	0.67	5.00*
17	MS.3	Comprehension	0.14	0.18	1.00	4.00*
18	MS.3	Application	0.20	0.05	1.29	0.20
19	MS.4	Knowledge	0.00	5.76+	0.33	1.00
20	MS.4	Comprehension	0.67	9.78*	0.00	0.00
21	MS.4	Application	1.00	0.07	0.33	1.00

### McNemar Chi-Square Tests for the 21 Pretest/Posttest Items for Each Geography 1050 Class Section and the Geosciences 2900 and Geography 1020 Class Sections (Observed Values)

\*Significant increase in the number of correct responses at the 95% level (critical value = 3.841, df =1).

\*Significant decrease in the number of correct responses at the 95% level (critical value = 3.841, df = 1).

Geography 1900a students incorrectly answered "Visible water vapor is drifting through the air" on the posttest while 4 chose this option on the pretest. A McNemar chi square test for match pairs was performed to determine whether this was statistically significant. The observed value was 4.50, indicating statistical significance at the 95% level of confidence. A misconception that water vapor is visible therefore appears to have generated among Geography 1900a interviewees.

There were two questions for which students enrolled in Geography 1900b made a statistically significant difference in the number of incorrect responses. This was observed for question 7 ("What are the *minimum* criteria that will cause the National Weather Service to issue a severe thunderstorm 'warning' for your county?") and question 11 ("Which city on the map is experiencing the coldest temperatures?") (Table 2). Question 7 referenced "Benchmark E.3: Explain appropriate safety precautions during severe weather," and question 11 referenced "Benchmark MS.1: Explain patterns of changing weather and how they are measured." Using Bloom's Taxonomy, question 7 was categorized as knowledge and question 11 was categorized as comprehension. A map was provided with question 11.

The question 7 correct response was "A storm is moving through your county that contains very large hail and/or strong damaging wind." Thirteen Geography 1900b students incorrectly answered "A storm is moving through your county that contains very heavy rain and/or dangerous cloud-to-ground lightning" on the posttest while 11 chose this option on the pretest. A McNemar chi square test for match pairs was performed to determine whether this was a statistically significant difference. The observed value was 0.50, indicating that this was not statistically significant at the 95% level of confidence. Five students incorrectly answered "The criteria will vary from place to place. It is therefore important to find out from local officials what criteria are used in your area" on the posttest while 2 chose this option on the pretest. A McNemar chi square test for match pairs was performed to determine whether this was performed to determine whether this option on the pretest.

difference. The observed value was 1.29, indicating that this was not statistically significant at the 95% level of confidence. Two students incorrectly answered "A thunderstorm is moving through your area that will last 20 minutes or longer" on both the posttest and the pretest. Thus, while there was a significant difference in the number of students who answered incorrectly, none of the incorrect answers were favored over the others.

The question 11 correct response was "There is no way to make this determination." Seven students incorrectly answered "Denver" on the posttest while 6 chose this option on the pretest. A McNemar chi square test for match pairs was performed to determine whether this was a statistically significant difference. The observed value was 0.11, indicating that this was not statistically significant at the 95% level of confidence. Three students incorrectly answered "Seattle" on the posttest while one chose this option on the pretest. A McNemar chi square test for match pairs was performed to determine whether this was a statistically significant difference. The observed value was 0.11, indicating that this was not statistically significant pairs was performed to determine whether this was a statistically significant difference. The observed value was 1.00, indicating that this was not statistically significance at the 95% level of confidence. Four students incorrectly answered New York on the posttest while three chose this option on the pretest. Thus, while there was a significant difference in the number of students who answered incorrectly, none of the incorrect answers were favored over the others. This suggests that the students answering incorrectly did not know the content adequately to do more than guess.

Similar to what was observed for the Geography 1900b class section, a statistically significant difference in the number of incorrect responses was made by students enrolled in Geography 1900c for question 11 ("Which city on the map is experiencing the coldest temperatures?") (Table 2). Seven students incorrectly answered "Denver" on the posttest while 5 chose this option on the pretest. A McNemar chi square test for match pairs was performed to determine whether this was a statistically significant increase. The observed value was 0.50, indicating that this was not

statistically significant at the 95% level of confidence. Five students incorrectly answered "Seattle" on the posttest while none of them chose this option the pretest. A McNemar chi square test for match pairs was performed to determine whether this was a statistically significant increase. The observed value was 5.00, indicating statistical significance at the 95% level of confidence.

The Geosciences 2900 Class Section. There was a statistically significant difference in the number of correct responses for question 12 ("If the low pressure center located between Denver and El Paso were to move northeast toward Chicago, what weather conditions would likely occur along the southern border of Michigan?") (Table 3). This question referenced "Benchmark MS.1: Explain patterns of changing weather and how they are measured" and was categorized as application. A map of the United States showing the current position of the low pressure system was provided with this question. What is noteworthy about this question was that it represented the only application question for which statistically significant improvements were observed for any of the Geography 1900, Geography 1050, and Geosciences 2900 course sections. In order to answer this question correctly, students needed to be familiar with circulation patterns around the low pressure system, locations and properties of air masses around the system, and types of weather occurring along the fronts. They also needed to be able to determine how these fronts and air masses would move as the low pressure system approached Chicago. The success that students had with this question suggests that Geosciences 2900 was effective in teaching the multiple concepts and processes necessary to answer this question correctly. This, therefore, provides evidence that students in this particular inquiry-based section are able to use inquiry to solve problems that have multiple components.

There was one question for which students enrolled in Geosciences 2900 made a statistically significant difference in the number of incorrect responses. This was observed for question 14 ("What happens to the air temperature and atmospheric pressure

as elevation increases?") (Table 3). This question referenced "Benchmark MS.2: Describe the composition and characteristics of the atmosphere" and was categorized as comprehension. The correct response was, "Both the air temperature and the atmospheric pressure decrease." The only other option that was chosen was, "The air temperature decreases, but the atmospheric pressure increases." The options "Both the temperature and the atmospheric pressure stay about the same" and "The air temperature decreases, but the atmospheric pressure stays about the same" were not chosen by any of the students on either the pretest or the posttest. All students therefore understood that the temperature decreases with an increase in elevation, but the misconception that atmospheric pressure increases in elevation persisted.

The Geography 1050 Class Sections. A statistically significant difference in the number of correct responses was observed by students enrolled in Geography 1050a for questions 10 ("What is a "cold front?") and 13 ("What are the two most abundant gases in the Earth's atmosphere?"), and for students enrolled in Geography 1050b for questions 1 ("Air masses are classified based on which two criteria?"), 7 ("What are the minimum criteria that will cause the National Weather Service to issue a severe thunderstorm 'warning' for your county?"), 8 ("A tornado 'watch' has been issued for your county. How should you interpret this?"), 10 ("What is a "cold front?"), 13 ("What are the two most abundant gases in the Earth's atmosphere?"), and 20 ("Which of the following statements about air pollution is true?") (Table 3). Questions 1 and 10 referenced "Benchmark MS.1: Explain patterns of changing weather and how they are measured," questions 7 and 8 referenced "Benchmark E.3: Explain appropriate safety precautions during severe weather," question 13 referenced "Benchmark MS.2: Describe the composition and characteristics of the atmosphere," and question 20 referenced "Benchmark MS.4: Describe the health effects of polluted air." Using Bloom's taxonomy, questions 1, 7, 10 and 13 were categorized as knowledge, and questions 8 and

20 were categorized as comprehension. There were no application questions for which a significant difference in the number of correct responses was observed.

It is interesting to note how well Geography 1050b students performed on questions 7 and 8 which referenced "Benchmark E.3: Explain appropriate safety precautions during severe weather." These students were able to discern the differences between severe weather "watches" and "warnings." Students in none of the inquirybased class sections exhibited a significant difference in the number of correct responses to questions 7 and 8 (Tables 2 and 3), and the students in the Geography 1900b class section actually exhibited a significant difference in the number of incorrect responses to question (Table 2). Students who enrolled in Geography 1050b were therefore acquiring essential understandings that were not being acquired by students enrolled in the inquirybased class sections. In spite of this, however, Geography 1050b students did not perform well on question 9, which was the application question related to Benchmark E.3 ("If you are in a school when a tornado 'warning' has been issued for your county, what is the first thing you should do?").

It is also interesting to note that the only questions for which there were statistically significant differences in the number of correct responses for *both* Geography 1050 class sections were questions 10 ("What is a "cold front?") and 13 ("What are the two most abundant gases in the Earth's atmosphere?"). As for question 10, a significant number of students choose the correct option ("the leading edge of a cold mass of air") on the posttest rather than the incorrect option of "a cold mass of air." This seems to indicate that Geography 1050 students were able to differentiate between a "front" and an "air mass," two concepts that, in the researcher's experience, are often confused with each other. There were no significant differences in the number of correct student responses for question 10 for any of the other class sections. This again indicates that students in the Geography 1050 class sections acquired essential understandings that were not acquired by students in the inquiry-based class sections.

There was a statistically significant difference in the number of incorrect responses for students enrolled in Geography 1050b for questions 11 ("Which city on the map is experiencing the coldest temperatures?") and 19 ("What name is given to solid particles or liquid droplets that are small enough to be suspended in the air?"). Question 11 referenced "Benchmark MS.1: Explain patterns of changing weather and how they are measured," and question 19 referenced "Benchmark MS.4: Describe health effects of polluted air." Using Bloom's Taxonomy, question 11 was categorized as comprehension and question 19 was categorized as knowledge.

With reference to question 11, twenty-seven students in Geography 1050b incorrectly answered "Denver" on the posttest while 11 chose this option on the pretest. A McNemar chi square test for match pairs was performed to determine whether this was a statistically significant decrease. The observed value was 9.85, indicating statistical significant at the 99% level of confidence.

With reference to question 19, the correct response was "particulate matter." Thirty-eight (38) of the 52 students chose the "crystalline nuclei" option on the posttest, while 13 chose this option on the pretest. A McNemar chi square test for matched pairs was performed to determine whether this was a statistically significant difference. The observed value was 21.55, indicating that it was statistically significant at the 99% level of confidence.

*The Geography 1020 Class Section.* For the Geography 1020 class section, the control group for which students were not presented with earth science concepts, there was a statistically significant difference in the number of correct responses for questions 6 ("What is the primary reason for seasonal variations on Earth?"), 16 ("What kind of change occurs when condensation takes place?), and 17 ("What natural process is occurring at C?") (Table 3). Question 6 referenced "Benchmark E.2: Describe seasonal changes in Michigan's weather," and questions 16 and 17 referenced "Benchmark MS.3: Explain the behavior of water in the atmosphere." Using Bloom's taxonomy, question 16

was categorized as knowledge, and questions 6 and 17 were categorized as comprehension. There were no application questions for which a significant difference in the number of correct responses was observed. There were no questions for which a significant difference in the number of incorrect responses was observed.

The values for questions 4, 7, and 12 are listed as "undefined" (Table 3) because they could not be calculated. The values for  $n_{11}$  (the number of subjects who answered correctly on the posttest but incorrectly on the pretest) and  $n_{22}$  (the number of subjects who answered incorrectly on the posttest but correctly on the pretest) were both "0" for all three questions, resulting in the following calculation for the observed value:

$$\chi^2 = [(0-0)^2] / (0+0) =$$
 Undefined

*Summary for All Class Sections.* For the Geography 1900 class sections, there were no significant differences in the number of correct responses for any of the application questions. Using Bloom's taxonomy, all questions for which statistically significant differences in the number of correct responses were observed were classified as knowledge or comprehension. The fact that no statistically significant improvements were observed for any of the application questions suggests that Geography 1900 is not developing problem solving skills as intended in the inquiry course design. Students are not able to apply the processes of science on paper and pencil examinations. This may suggest that inquiry is not taking place within Geography 1900 as intended.

For the Geosciences 2900 class section, there was a statistically significant difference in the number of correct responses *only* for question 12. This was noteworthy because it was an application question. In fact, it was also the only application question for which a statistically significant improvement was observed for *any* of the class sections. This suggests that Geosciences 2900 students *are* able to apply the processes of

science on paper and pencil examinations. This provides some evidence that inquiry is taking place as intended.

For the Geography 1050 class sections, there was a statistically significant difference in the number of correct responses for several knowledge questions. These questions were related to fronts and air masses, the two most abundant gases in the atmosphere, the classification of air masses, and the criteria for a severe thunderstorm. There were also statistically significant improvements for the Geography 1050b class section on comprehension questions related to air pollution and the interpretation of a tornado watch. No statistically significant improvements were observed for any of the application questions. Overall, the Geography 1050 class sections made statistically significant improvements than any of the other class sections. This data suggest that Geography 1050 was more effective at this level than were the inquiry-based sections.

For the Geography 1020 class section, there was a statistically significant difference in the number of correct responses for one knowledge question and two comprehension questions. This provides evidence that factors *in addition to* attendance in earth science courses result in growth in students' knowledge and comprehension of atmospheric science concepts. Students are maturing and learning of their own accord. It is also possible that some of the Geography 1020 students were enrolled in an earth science course. However, the researcher did not ask these students whether they were also taking Geography 1050 or Geography 1900.

Misconceptions were developed by students in several of the class sections. The misconceptions were not universal. Each class section resulted in the formation of unique misconceptions. Posttest responses for question 7 revealed that students in Geography 1900b constructed a misconception that a severe thunderstorm is categorized by factors other than large hail and/or damaging wind. Posttest responses for question 11 revealed that students in Geography 1900c and Geography 1050b not only displayed a

statistically significant change in the number of incorrect responses, but students in Geography 1900c incorrectly associated the coldest temperatures on a national weather map with Seattle (perhaps because Seattle was the most northern location) and students in Geography 1050b incorrectly associated the coldest temperatures on the national weather map with Denver (perhaps because Denver was the closest location to the center of the low pressure system). It is worth noting, however, that students in Geography 1900b did not associate the coldest temperatures with either Seattle or Denver, even though they also displayed a statistically significant change in the number of incorrect responses for question 11. Posttest responses for question 14 revealed that students in Geosciences 2900 constructed a misconception that atmospheric pressure increases with an increase in elevation. Posttest responses for question 17 revealed that students in Geography 1900a constructed a misconception that water vapor is invisible.

Unlike the earth science class sections, misconceptions about meteorology were not generated within the control group. There were no questions for which students in Geography 1020, a human geography course, made a statistically significant change in the number of incorrect responses. This was to be expected, given that students enrolled in this class section were not being presented with earth science concepts. This provides evidence that the misconceptions that were observed in the earth science class sections were indeed developed by the students during class sections, and were not random.

Finally, it is clear that not all of the Michigan benchmark standards were adequately addressed in the inquiry-based class sections. As a result, it appears that some misconceptions among pre-service teachers were not confronted. One example of this was observed. Misconceptions related to the minimum criteria for a severe thunderstorm warning were developed by students enrolled in Geography 1900b. However, students enrolled in Geography 1050b made statistically significant improvements in their understandings of those minimum criteria.

### **Background Analysis**

The pretests contained a series of questions designed to elicit general information about students' backgrounds. These background questions are in Appendix E. This section will examine the influence of these background areas on students' understandings of and proficiency with atmospheric science content. A background question about how comfortable students felt about using a computer was thrown out because there was not enough variety in the responses.

All students were asked to report his or her grade point average. Scatter graphs and trend lines showing the relationship between grade point averages and pretest scores for the eight class sections are in Figures 1, 2, and 3. The graphs show an upward trend in pretest scores with increasing grade point averages. Pearson "r" values were calculated to determine whether these trends were statistically significant. Geography 1900d and Geography 1050a were the only class sections for which statistical significant correlations were observed. The r value of 0.57 for the Geography 1900d class section was significant at the 99% level of confidence (p-value = 0.01). The r value of 0.53 for the Geography 1050a class section was significant at the 95% level of confidence (pvalue = 0.04).

Scatter graphs and trend lines showing the relationship between grade point averages and pre- to posttest difference scores were developed for each class section. These graphs are in Figures 4, 5, and 6. The graphs for Geography 1900b, Geography 1900d, Geosciences 2900, Geography 1050b, and Geography 1020 show an upward trend in pre- to posttest difference scores with increasing grade point averages. The graphs for Geography 1900a, Geography 1900c, and Geography 1050a show a downward trend in pre- to posttest difference scores with increasing grade point averages. Pearson "r" values were calculated to determine whether these trends were statistically significant. The p-values were all greater than 0.05, indicating that none of the trends were statistically significant.







Figure 1. Relationship between Grade Point Average and Pretest Scores for the Geography 1900a, Geography 1900b, and Geography 1900c Class Sections.







Figure 2. Relationship between Grade Point Average and Pretest Scores for the Geography 1900d, Geosciences 2900, and Geography 1020 Class Sections.

All students enrolled in Geography 1050 were asked to state their program of study. There were 5 education students and 11 non-education students enrolled in Geography 1050a. There were 16 education students and 35 non-education students enrolled in Geography 1050b.

Independent sample t-tests were completed to determine whether there were statistically significant differences between the pretest scores for education students and the pretest scores for non-education students. There were no significant differences for





Figure 3. Relationship between Grade Point Average and Pretest Scores for the Geography 1050a and Geography 1050b Class Sections.







Figure 4. Relationship between Grade Point Average and Pre- to Posttest Difference Scores for the Geography 1900a, Geography 1900b, and Geography 1900c Class Sections.







Figure 5. Relationship between Grade Point Average and Pre- to Posttest Difference Scores for the Geography 1900d, Geosciences 2900, and Geography 1020 Class Sections.

either of the class sections. The p-value for Geography 1050a was 0.83, and the p-value for Geography 1050b was 0.26. Independent sample t-tests were performed to determine whether there were statistically significant differences between the pre- to posttest difference scores for two categories, education students and non-education students. There were no statistically significant differences for either of the curriculum categories of students. The p-value for Geography 1050a was 0.45, and the p-value for Geography 1050b was 0.59.





Figure 6. Relationship between Grade Point Average and Pre- to Posttest Difference Scores for the Geography 1050a and Geography 1050b Class Sections.

All students were asked to report how often they used the library by choosing one of the following five options: "never," "rarely, only when required," "occasionally," "frequently," and "as often as possible." Over 85% of the students who responded to this question chose either "rarely, only when required" or "occasionally." The other three options were not included in the analysis of library attendance because there were not enough instances of students choosing those options.

Independent sample t-test were performed for all eight class sections to determine whether there were statistically significant differences between the mean pretest scores of those who reported that they went to the library "rarely, only when required" and those who reported that they went to the library "occasionally." The only class section for which a significant difference was observed was Geography 1900d. The mean pretest score for the Geography 1900d students who reported "rarely, only when necessary" (n = 5) was 0.305, while the mean pretest score for those who reported "occasionally" (n = 13) was 0.462. This was statistically significant at the 95% level of confidence (p-value = 0.04).

Independent sample t-tests were performed for all eight class sections to determine whether there were statistically significant differences between the pre- to posttest difference scores of those who reported that they went to the library "rarely, only when required" and those who reported that they went to the library "occasionally." Significant differences were observed for the Geography 1050b, Geography 1900d, and Geosciences 2900 class sections. The mean pre- to posttest difference score for the Geography 1050b students who reported "rarely, only when required" (n = 16) was -0.009, while the mean pre- to posttest difference score for the Geography 1050b students who reported "occasionally" (n = 23) was 0.089. This was significant at the 99% level of confidence (p-value = 0.00). The mean pre- to posttest difference score for the Geography 1900d students who reported "rarely, only when necessary" (n = 5) was 0.171, while the mean pre- to posttest difference score for the Geography 1900d students

who reported "occasionally" (n = 13) was 0.037. This was significant at the 95% level of confidence (p-value = 0.04). The mean pre- to posttest difference score for the Geosciences 2900 students who reported "rarely, only when necessary" (n = 6) was 0.206, while the mean pre- to posttest difference score for the Geosciences 2900 students who reported "occasionally" (n = 11) was 0.013. This was significant at the 99% level of confidence (p-value = 0.00).

All students were asked to report the average number of classes that they miss per semester by choosing one of the following five options: "0 to 1," "2 to 4," "5 to 7," "8 to 10," and "more than 10." Over 88% of the students who responded to this question chose either "0 to 1" or "2 to 4." The other three options were not included in the analysis of class attendance because there were not enough instances of students choosing those options. In addition, Geography 1020 was not included in the analysis of class attendance because there was not enough variety in the responses.

Independent sample t-test were performed for all class sections except Geography 1020 to determine whether there were statistically significant differences between the mean pretest scores of those who reported that they miss an average of "0 to 1" classes per semester and those who reported that they miss an average of "2 to 4" classes per semester. Significant differences were observed for Geography 1050b. The mean pretest score for the Geography 1050b students who reported "0 to 1" (n = 18) was 0.513, while the mean pretest score for the Geography 1050b students who reported "2 to 4" (n = 25) was 0.410. This was significant at the 99% level of confidence (p-value = 0.01).

Independent sample t-test were performed for all class sections except Geography 1020 to determine whether there were statistically significant differences between the mean pre- to posttest difference scores of those students who reported that they miss an average of "0 to 1" classes per semester and those who reported that they miss an average of "2 to 4" classes per semester. No significant differences were observed for any of the class sections.

All students were asked to report their resident status by choosing one of the following two options: "I live on campus" and "I am a commuter."

Independent sample t-test were performed for all class sections to determine whether there were statistically significant differences between the mean pretest scores of those who reported that they live on campus and those who reported that they commute. No significant differences were observed for any of the class sections. Independent sample t-test were performed for all class sections to determine whether there were statistically significant differences between the mean pre- to posttest difference scores of those who reported that they live on campus and those who reported that they commute. No significant differences were observed for any of the class sections.

Summary of the Background Analysis, Pretest Scores. For all class sections, scatter graphs and trend lines showing the relationship between grade point averages and pretest scores were upward. The trends were statistically significant for the Geography 1900d and Geography 1050a class sections. For the Geography 1900d class section, there was a statistically significant differences between the mean pretest scores of those who reported that they went to the library "rarely, only when required" and those who reported that they went to the library "occasionally." For the Geography 1050b class section, there was a statistically significant difference between the mean pretest scores of those who reported that they miss an average of "0 to 1" classes per semester and those who reported that they miss an average of "2 to 4" classes per semester. These findings suggest a general pattern that students who received higher grades in previous courses, who went to the library more often than was necessary, and who attended their other courses regularly received a higher score on the research test instrument. They may have also had a more extensive understanding of atmospheric science from which they could draw from and build upon at the onset of the earth science courses.

There is no evidence that resident status (a campus resident versus a commuter) or program of study (an education program versus a non-education program) made any

difference in helping students to build a more extensive understanding of atmospheric science that they could draw from at the onset of the earth science courses.

Summary of the Background Analysis, Pre- to Posttest Difference Scores. Library attendance was the only background variable that appeared to have any relationship with students' abilities to construct understanding about atmospheric science *during* the earth sciences courses. The evidence does suggest that this relationship is different for students in the inquiry-based class sections than for students in the Geography 1050 class sections. For the Geography 1050b, Geosciences 2900, and Geography 1900d class sections, there was a statistically significant difference between the pre- to posttest difference scores for students who reported attending the library "occasionally" and those who reported attending the library "rarely, only when necessary." For Geography 1050b, the mean preto posttest difference score for students who reported attending the library "occasionally" was higher than the mean pre- to posttest difference score for those who reported attending the library "rarely, only when necessary." For Geosciences 2900 and Geography 1900d, the mean pre- to posttest difference score for students who reported attending the library "rarely, only when necessary" was higher than the mean pre- to posttest score for those who reported attending the library "occasionally." Thus, it is noteworthy that Geosciences 2900 and Geography 1900d students who reported spending more time in the library fared worse. This suggests that a stronger emphasis on investigative approaches to learning leads to a decreased emphasis on book-based knowledge.

## **Classroom Observations**

Hand-written observations of 39 classroom sessions were made by the researcher during the Spring 2005 semester, including 9 Geography 1900b sessions taught by "Instructor 1," 7 Geography 1900d sessions taught by "Instructor 2," 7 Geosciences 2900

sessions taught by "Instructor 2," 11 Geography 1050b lecture sessions taught by the primary instructor for Geography 1050, and 5 Geography 1050b laboratory sessions taught by a graduate student teaching assistant.

The researcher always sat at a location that was conducive for observing all areas of the classroom. For large lecture halls, this was usually at the highest level in the back of the room. For small laboratory classrooms, this was usually at one of the corners of the room. The researcher did not interact with the instructor or with students while observations were being made. The observations made by the researcher focused on classroom behaviors that included, but were not limited to, the pedagogy employed by the instructor, the interactions that occurred among the students, and the interactions that occurred between the teacher and the students. At least one observation was made per minute, although several observations per minute were usually made. All observations were later word processed by the researcher.

### The SAMPI Lesson Observation System

All classroom observations were coded using The SAMPI Lesson Observation System, an instrument developed by the Science and Mathematics Program Improvement (SAMPI) faculty and staff at Western Michigan University. SAMPI is part of the Mallinson Institute for Science Education. This observation system is described as follows (Science and Mathematics Program Improvement, 2003c; p. 1):

The SAMPI Lesson Observation System is a comprehensive protocol for observing, analyzing, and reporting data from observations of contentbased lessons in kindergarten through twelfth grade classrooms. It is based on Michigan and national teaching and learning standards in core subjects areas with an orientation toward inquiry and investigative approaches to learning.

Though designed for kindergarten through twelfth grade classrooms, the instrument is not limited to this level and may be applied to college level classrooms.

The instrument has two versions: the "mentoring" version designed "so that direct feedback can be given to a teacher or [a] small group of teachers about the specific lesson(s) observed," (Science and Mathematics Program Improvement, 2003c; p. 1), and the "snapshot" version designed for "observing multiple lessons across classrooms, compiling and analyzing the data, and identifying strengths and limitations" (Science and Mathematics Program Improvement, 2003c; p. 1). The "snapshot" version was used in this study.

The instrument guides the observer through the following four steps (Science and Mathematics Program Improvement, 2003c; p, 1):

The first step involves having trained observers watch a complete lesson [and] take notes... The second step is for observers, using their notes and memory of the lesson, to complete a debriefing form. This [is a] five-part instrument [that] provides observers with a systematic way to assess the key elements of a lesson by scoring a set of criteria on a 7-point scale and providing rationale for the score. The score is intended to "anchor" the observer's judgment about the particular criteria. In the snapshot version, overall ratings and a lesson summary rating are also completed by the observer. The first section of the debriefing instrument includes basic information about the lesson—date, length, purpose, description, materials used, etc. The remainder of the instrument is divided into four sections. one each for four major components of the lesson: planning and organization, implementation, content, and classroom culture in which the lesson is conducted. Each of these sections includes criteria based on Michigan and national teaching and learning standards. The third step concerns compilation and analysis of the ratings. The fourth step relates to reporting and use of the data.

In order to fulfill the requirement that the observer be "trained," the researcher attended a two-day training session presented by Dr. Mark Jenness, Director of the Science and Mathematics Program Improvement (SAMPI). This training session was designed to help observers use and interpret the criteria, and to rate the lessons in ways consistent with the consensus ratings.

The instrument rates lessons based on 21 questions formulated to fit three of the four main components of the lesson, namely the *implementation of the lesson*, the *content* 

*of the lesson*, and the *classroom culture*. Higher ratings indicate a greater consistency with state and national standards and with inquiry and investigative approaches toward teaching and learning. Ratings of 1 and 2 are considered to be low. Ratings of 3, 4, and 5 are considered to be in the middle. Ratings of 6 and 7 are considered to be high.

Seven of the 21 questions are related to the *implementation of the lesson*. These questions are used to rate the confidence of the instructor, teacher-student interactions, classroom management, the pace of the lesson, student-student interactions, reflection on the lesson, and the wrap-up of the lesson.

Eight of the 21 questions are related to the *content of the lesson*. These questions are used to rate the importance of the content, the intellectual engagement of the students, the portrayal of the subject matter, the competency of the instructor, the connection of the content to other lessons, the connection of the content to other subjects, the application of the content to the real-world, and the use of abstractions.

Six of the 21 questions are related to the *classroom culture*. These questions are used to rate the active participation of students, the respect shown by the instructor for students' ideas, the respect shown by the students for the ideas of other students, the classroom climate for the generation of ideas, teacher-student collaborative relationships, and student-student collaborative relationships..

Detailed definitions for each of the questions are provided within the guidelines of the instrument. These definitions are further clarified through "Focus Questions/Statements" and "Examples." For example, the *implementation of the lesson* question related to the teacher-student interactions is as follows (Science and Mathematics Program Improvement, 2003b; p, 4):

Periods of teacher-student interaction were probing and substantive (questioning and dialog emphasized higher-order thinking and deep understanding and exposed students' prior knowledge).

The "Focus Questions/Statements" for this question are as follows (Science and Mathematics Program Improvement, 2003a; p, 5):

High-level questions (application, analysis, synthesis, evaluation) are used to challenge student thinking; other forms of dialog are used that lead to student understanding of the lesson concepts (imparting information, offering ideas about where to search out more information, asking for more explanation, etc.)

"Examples" are provided as follows (Science and Mathematics Program Improvement,

2003a; p, 5):

Substantive questions are asked of individuals or small groups, and the whole group; questions challenge students to justify or provide evidence for their ideas and contentions; apply their ideas to other science and/or real-world situations, gather ideas from various experiences to understand something, and/or evaluate a situation; questions challenge students to think about alternative solutions and differences of opinion.

Following the questions for each of the three components of the lesson (the

*implementation of the lesson*, the *content of the lesson*, and the *classroom culture*), an "overall" rating for that component is assigned using the 7-point scale. This rating represents the observer's "best subjective judgment of the appropriateness and quality" (Science and Mathematics Program Improvement, 2003b; p. 5) of the lesson for that component. An "overall" rating for a lesson component is not necessarily intended to be the numeric average of the ratings assigned to the indicator questions. There may be "other factors that influence the overall rating" (Science and Mathematics Program Improvement, 2003b; p. 5).

Finally, a *summary* rating of the entire lesson is assigned using the 7-point scale. This rating is based not only on the ratings for the three components of the lesson described above, but also on answers given for several questions related to another lesson component related to the *planning/organization of the lesson*. The questions representing this component are not rated on the 7-point scale, but are primarily "Yes" and "No"

questions. For example, one of the *planning/organization of the lesson* questions is as follows (Science and Mathematics Program Improvement, 2003b; p, 2):

Were investigative tasks essential elements of the lesson plan (e.g., manipulation of information to help make sense of content, elements of problem-solving situations, connections to real-world experiences)?

The *summary* rating is useful for getting "an overview of the nature and quality of lessons being conducted" (Science and Mathematics Program Improvement, 2003b; p. 15), and can be helpful "for looking at change over time among all the classrooms, as long as the sampling is credible" (Science and Mathematics Program Improvement, 2003b; p. 15).

### The Pilot Study

A pilot study was performed during the Fall 2004 semester. Hand-written observations were made by the researcher for 12 lecture sessions of Geography 1050a. These observations were coded using the SAMPI Lesson Observation System.

There were three purposes for the pilot study: First, it was important for the researcher to gain practice and experience at recording classroom observations in ways that were useful within the context of the SAMPI Lesson Observation System. The researcher had no prior experience at making and recording such observations. This trial application was therefore conducted a semester prior to the larger study.

Second, it was important for the researcher to gain practice and experience at using the SAMPI Lesson Observation System before using it within the context of the larger study. In order for the analysis to be valid, it was necessary to rate lessons in ways that were consistent with the definitions provided for each of the 21 instrument questions rather than according to the researcher's own biases and interpretations of the questions. Performing a pilot study gave the researcher experience at interpreting the instrument questions appropriately.

Third, the pilot study was used as an indicator that the researcher was using the SAMPI Lesson Observation System consistently across lessons. The Geography 1050

course was taught by the same instructor during both the Fall 2004 and the Spring 2005 semesters, and very similar content was presented during both semesters. The ratings obtained for the 12 Geography 1050a lecture sessions observed during the pilot study (Fall 2004) were compared with the ratings obtained for the 11 Geography 1050b lecture sessions observed during the main study (Spring 2005). Independent sample t-tests were performed to compare the mean ratings between the two semesters for the seven *implementation of the lesson* questions, for seven of the eight *content of the lesson* questions, for the "overall" *implementation of the lesson* rating, for the "overall" *content of the lesson* rating, for the "overall" *content of the lesson* rating, for the summary rating. The *content of the lesson* question related to the importance of the content was not analyzed because all classroom sessions for both semesters were rated the highest possible value of 7.

The p-values for the *implementation of the lesson* questions and the "overall" *implementation of the lesson* rating are in Table 4. The p-values for the *content of the lesson* questions and the "overall" *content of the lesson* rating are in Table 5. The p-values for the *classroom culture* questions and the "overall" *classroom culture* rating are in Table 6. The p-value for the "overall" *summary* rating is in Table 6.

There were no significant differences for any of the questions or for any of the "overall" ratings. It was therefore concluded that the researcher was able to apply the instrument in a consistent way across lessons.

#### The Classroom Observation Ratings

The mean "overall" rating for the *implementation of the lesson* component for each class section is in Table 7. The mean ratings for the seven *implementation of the lesson* questions for each class section are in Table 8.

The mean "overall" rating for the *content of the lesson* component for each class section is in Table 9. The mean ratings for seven of the eight *content of the lesson* 

Implementation Question	Geog 1050a	Geog 1050b	Difference	p-value
Instructor confidence	5.9	6.2	0.3	0.09
Teacher-student interaction	1.4	2.4	1.0	0.14
Classroom management	2.3	2.5	0.2	0.86
Pace of the lesson	4.3	4.5	0.2	0.48
Student-student interaction	1.5	2.1	0.6	0.40
Reflection on the lesson	1.6	2.2	0.6	0.42
Wrap-up of the lesson	1.5	2.1	0.6	0.42
Overall implementation rating	2.5	3.0	0.5	0.37

## A Comparison of the Mean Ratings of the *Implementation of the Lesson* Questions Between the Geography 1050a Section and the Geography 1050b Section

#### Table 5

## A Comparison of the Mean Ratings of the *Content of the Lesson* Questions Between the Geography 1050a Section and the Geography 1050b Section

Content Question	Geog 1050a	Geog 1050b	Difference	p-value
Intellectual engagement of students	2.6	2.6	0.0	0.94
Portrayal of subject matter	1.2	1.8	0.6	0.27
Instructor competence	6.7	7.0	0.3	0.10
Connection to other lessons	2.3	2.0	-0.3	0.22
Connection to other subjects	2.3	2.0	-0.3	0.22
Application to the real world	3.0	2.5	-0.5	0.40
Use of abstractions	5.6	5.4	-0.2	0.77
Overall content rating	3.9	4.1	0.2	0.44

Culture Question	Geog 1050a	Geog 1050b	Difference	p-value
Active participation of students encouraged	3.2	3.2	0.0	0.99
Teacher's respect for students' ideas	3.2	2.7	-0.3	0.56
Students' respect for other students' ideas	2.6	2.4	-0.2	0.83
Students encouraged to generate ideas	3.8	3.8	0.0	0.98
Teacher-student collaborative relationships	1.8	1.9	0.1	0.83
Student-student collaborative relationships	2.0	2.5	0.5	0.46
Overall culture rating	3.0	2.9	-0.1	0.89
Overall summary rating	3.2	3.4	0.2	0.70

A Comparison of the Mean Ratings of the *Classroom Culture* Questions and the "Overall" *Summary* Ratings Between the Geography 1050a Section and the Geography 1050b Section

#### Table 7

## Mean "Overall" Implementation of the Lesson Rating for Each Class Section

Class Section	Instructor	Approach	Sessions (n)	Mean Rating
Geography 1050b (Lecture)	3	Traditional	11	3.0
Geography 1050b (Laboratory)	TA*	Traditional	5	3.2
Geography 1900b	1	Inquiry	9	5.0
Geography 1900d	2	Inquiry	7	4.4
Geosciences 2900	2	Inquiry	7	5.1

\*This section was taught by a teaching assistant who was a graduate student.

Class Section	Instructor confidence	Teacher- student interaction	Classroom management	Pace of the lesson	Student- student interaction	Reflection on the lesson	Wrap-up of the lesson
1+	6.2	2.4	2.5	4.5	2.1	2.2	2.1
2++	5.0	3.0	4.0	4.0	4.2	3.0	1.0
$3^{\pm}$	5.0	4.8	5.1	6.0	4.9	4.9	4.3
$4^{\pm\pm}$	5.0	3.3	4.7	4.0	5.4	4.4	3.6
5#	7.0	5.4	5.4	4.0	5.4	5.4	4.3

## Mean Ratings for Each Implementation of the Lesson Question for Each Class Section

<sup>+</sup>Geography 1050b lecture section

++Geography 1050b laboratory section

<sup>±</sup>Geography 1900b section

<sup>±±</sup>Geography 1900d section

<sup>#</sup>Geography 2900 section

#### Table 9

## Mean "Overall" *Content of the Lesson* Rating for Each Class Section

Class Section	Instructor	Instructor Approach		Mean Rating
Geography 1050b (Lecture)	3	Traditional	11	4.1
Geography 1050b (Laboratory)	TA*	Traditional	5	3.0
Geography 1900b	1	Inquiry	9	4.8
Geography 1900d	2	Inquiry	7	4.6
Geosciences 2900	2	Inquiry	7	4.1

\*This section was taught by a teaching assistant who was a graduate student.

questions for each class section are in Table 10. The *content of the lesson* question related to the importance of the content was not analyzed because all 39 classroom sessions were rated the highest possible value of 7. It was therefore concluded that none of the classroom sessions were "focused on trivial or extraneous concepts and skills" (Science and Mathematics Program Improvement; 2003a, p. 7).

The mean "overall" rating for the *classroom culture* component for each class section is in Table 11. The mean ratings for the six *classroom culture* questions for each class section are in Table 12.

The mean "overall" *summary* rating for each class section is in Table 13. ANOVA tests were performed on the mean "overall" *implementation of the lesson* ratings, the mean "overall" *content of the lesson* ratings, the mean "overall" *classroom culture* ratings, and the mean "overall" *summary* ratings to determine whether there were statistically significant differences in these mean ratings across class sections. If the ANOVA tests detected statistically significant differences across sections, post-hoc Tukey HSD tests were performed to determine the source of the differences. Similarly, ANOVA tests and Post-hoc Tukey HSD tests were performed on the mean ratings for the seven *implementation of the lesson* questions, seven of the eight *content of the lesson* questions, and the six *classroom culture* question in order to more precisely determine the nature of the differences between classroom groups. The SPSS<sup>®</sup> statistical software package (SPSS, 2003b) was used to conduct the ANOVA and Tukey HSD tests.

A p-value of 0.00 was obtained from the ANOVA tests for the four "overall" ratings, indicating statistical significance at the 99% level of confidence. Post-hoc Tukey tests were performed to determine the source of the differences. The results of the Tukey tests for the "overall" *implementation of the lesson* ratings are in Table 14. The results of the Tukey tests for the "overall" *content of the lesson* ratings are in Table 15. The results of the Tukey tests for the "overall" *classroom culture* ratings are in Table 16. The results of the Tukey tests for the "overall" *summary* ratings are in Table 17.

Mean Ratings for Each Content of the Lesson Qu	estion
for Each Class Section	

Class Section	Intellectual engagement of students	Portrayal of subject matter	Instructor competence	Connection to other lessons	Connection to other subjects	Application to the real world	Use of abstractions
1 <sup>+</sup>	2.6	1.8	7.0	2.0	2.0	2.5	5.4
2**	3.2	4.0	5.2	1.0	1.0	1.0	1.0
$3^{\pm}$	5.1	4.6	7.0	3.8	1.0	3.1	6.0
$4^{\pm\pm}$	5.4	3.6	7.0	3.3	1.0	2.6	5.0
5#	5.7	6.0	7.0	2.7	1.4	2.3	3.0

<sup>+</sup>Geography 1050b lecture section

++Geography 1050b laboratory section

<sup>±</sup>Geography 1900b section

<sup>±±</sup>Geography 1900d section

<sup>#</sup>Geography 2900 section

## Table 11

# Mean "Overall" *Classroom Culture* Rating for Each Class Section

Class Section	Instructor	Approach	Sessions (n)	Mean Rating
Geography 1050b (Lecture)	3	Traditional	11	2.9
Geography 1050b (Laboratory)	TA*	Traditional	5	3.2
Geography 1900b	1	Inquiry	9	5.0
Geography 1900d	2	Inquiry	7	5.3
Geosciences 2900	2	Inquiry	7	5.9

\*This session was taught by a teaching assistant who was a graduate student.

Class Section	Active participation of students' encouraged	Teacher's respect for students' ideas	Students' respect for other students' ideas	Students encouraged to generate ideas	Student- student collaborative relationships	Teacher- student collaborative relationships
$1^{+}$	3.2	2.7	2.4	3.8	1.9	2.5
2++	4.4	3.8	4.0	2.8	3.4	1.8
$3^{\pm}$	5.4	4.9	5.0	5.1	5.3	4.8
$4^{\pm\pm}$	5.7	3.9	5.9	4.4	5.9	5.3
5#	6.0	5.7	7.0	5.4	5.6	5.1

## Mean Ratings for Each Classroom Culture Question for Each Class Section

<sup>+</sup>Geography 1050b lecture section

<sup>++</sup>Geography 1050b laboratory section

<sup>±</sup>Geography 1900b section

<sup>±±</sup>Geography 1900d section

<sup>#</sup>Geography 2900 section

#### Table 13

## Mean "Overall" Summary Rating for Each Class Section

Class Section	Instructor	Approach	Sessions (n)	Mean Rating
Geography 1050b (Lecture)	3	Traditional	11	3.4
Geography 1050b (Laboratory)	TA*	Traditional	5	3.2
Geography 1900b	1	Inquiry	9	5.0
Geography 1900d	2	Inquiry	7	4.7
Geosciences 2900	2	Inquiry	7	5.3

\*This section was taught by a teaching assistant who was a graduate student.

•

	Geography 1050b Laboratory	Geography 1900b Instructor 1	Geography 1900d Instructor 2	Geosciences 2900 Instructor 2
Geography 1050b (Lecture)	0.99	0.00**	0.04*	0.00**
Geography 1050b (Laboratory)		0.02*	0.23	0.02*
Geography 1900b (Instructor 1)			0.73	0.99
Geography 1900d (Instructor 2)				0.66

# Tukey HSD Tests for the "Overall" *Implementation of the Lesson* Ratings for Each Class Section Pair (p-values)

\*Significant at the 95% level of confidence

\*\*Significant at the 99% level of confidence

#### Table 15

## Tukey HSD Tests for the "Overall" Content of the Lesson Ratings for Each Class Section Pair (p-values)

	Geography 1050b Laboratory	Geography 1900b Instructor 1	Geography 1900d Instructor 2	Geosciences 2900 Instructor 2
Geography 1050b (Lecture)	0.00**	0.04*	0.32	1.00
Geography 1050b (Laboratory)		0.00**	0.00**	0.00**
Geography 1900b (Instructor 1)			0.93	0.12
Geography 1900d (Instructor 2)				0.54

\*Significant at the 95% level of confidence

\*\*Significant at the 99% level of confidence
## Tukey HSD Tests for the "Overall" *Classroom Culture* Ratings for Each Class Section Pair (p-values)

	Geography 1050b Laboratory	Geography 1900b Instructor 1	Geography 1900d Instructor 2	Geosciences 2900 Instructor 2
Geography 1050b (Lecture)	0.99	0.00**	0.00**	0.00**
Geography 1050b (Laboratory)		0.06	0.03*	0.00**
Geography 1900b (Instructor 1)			0.99	0.57
Geography 1900d (Instructor 2)				0.88

\*Significant at the 95% level of confidence

\*\*Significant at the 99% level of confidence

## Table 17

## Tukey HSD Tests for the *Summary* Ratings for Each Class Section Pair (p-values)

	Geography 1050b Laboratory	Geography 1900b Instructor 1	Geography 1900d Instructor 2	Geosciences 2900 Instructor 2
Geography 1050b (Lecture)	0.99	0.00**	0.02*	0.00**
Geography 1050b (Laboratory)		0.01**	0.04*	0.00**
Geography 1900b (Instructor 1)			0.97	0.97
Geography 1900d (Instructor 2)				0.74

\*Significant at the 95% level of confidence

\*\*Significant at the 99% level of confidence

A p-value of 0.00 was obtained from the ANOVA tests for the seven *implementation of the lesson* questions, the seven *content of the lesson* questions, and the six *classroom culture* questions, indicating statistical significance at the 99% level of confidence. Post-hoc Tukey tests were performed to determine the source of the differences. The results of the Tukey tests for the seven *implementation of the lesson* questions are in Table 18. The results of the Tukey tests for the seven *content of the lesson* questions are in Table 19. The results of the Tukey tests for the six *classroom culture* questions are in Table 20.

### Interpretation of the Ratings

*The Geography 1050b Class Section.* For the Geography 1050b laboratory section, mean ratings on or near 3.0 (the low end of the middle of the 7-point scale), were observed for the four "overall" ratings (Tables 7, 9, 11, and 13). For the Geography 1050b lecture section, mean ratings on or near 3.0 were observed for the "overall" ratings except *content of the lesson*, for which a mean rating of 4.1 (near the center of the middle of the scale) was observed (Tables 7, 9, 11, and 13). A statistically significant difference between the Geography 1050b lecture section and the Geography 1050b laboratory section was observed for the "overall" *content of the lesson* rating (Table 15). Overall, these findings suggest that Geography 1050b was more traditional than inquiry-based. For the *implementation of the lesson* and *classroom culture* components, the lecture and laboratory section were taught with similar consistency relative to the national and state standards. For the *content of the lesson* component, the lecture section was more consistent with the national and state standards than was the laboratory section.

For the Geography 1050b lecture section, the questions with regard to instructor confidence and instructor competence rated between 6.0 and 7.0 (the high end of the scale) (Tables 8 and 10). The instructor was rated as "knowledgeable about the topic of the lesson and [was] able to respond to student questions" (Science and Mathematics

Section Pairs <sup>±</sup>	Instructor confidence	Teacher- student interaction	Classroom management	Pace of the lesson	Student- student interaction	Reflection on the lesson	Wrap-up of the lesson
1, 2	0.00**	0.83	0.20	0.55	0.05*	0.77	0.78
1, 3	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.06
1,4	0.00**	0.45	0.00**	0.44	0.00**	0.00**	0.43
1, 5	0.00**	0.00**	0.00**	0.44	0.00**	0.00**	0.10
2, 3	1.00	0.06	0.54	0.00**	0.89	0.09	0.02*
2, 4	1.00	0.99	0.88	1.00	0.54	0.35	0.11
2, 5	0.00**	0.00**	0.34	1.00	0.54	0.03*	0.03*
3, 4	1.00	0.09	0.97	0.00**	0.93	0.96	0.91
3, 5	0.00**	0.78	0.99	0.00**	0.93	0.92	1.00
4, 5	0.00**	0.00**	0.84	1.00	1.00	0.61	0.94

#### Tukey HSD Tests for Each Implementation of the Lesson Question for Each Class Section Pair (p-values)

<sup>±</sup>Numbers correspond to the same class sections as defined in table 8.

\*Significant at the 95% level of confidence

\*\*Significant at the 99% level of confidence

Program Improvement; 2003a, p. 5), and "had an adequate grasp of the lesson concepts to help facilitate learning without giving or expecting 'canned' answers or solutions" (Science and Mathematics Program Improvement, 2003a; p. 7). However, mean ratings between 1.8 and 3.2 (the low to low middle end of the scale) were observed for 15 of the 20 questions, including five *implementation of the lesson* questions, five *content of the lesson* questions, and five *classroom culture* questions. This provides additional evidence that, overall, the Geography 1050b lecture section was traditional instruction rather than inquiry-based.

For the Geography 1050b laboratory section, there were no questions for which

Section	Intellectual engagement	Portrayal of subject	Instructor	Connection to other	Connection to other	Application to the	Use of
Pairs <sup>±</sup>	of students	matter	competence	lessons	subjects	real world	abstractions
1, 2	0.94	0.02*	0.00**	0.14	0.00**	0.02*	0.00**
1, 3	0.00**	0.00**	1.00	0.00**	0.00**	0.62	0.68
1,4	0.00**	0.05*	1.00	0.01**	0.00**	1.00	0.95
1, 5	0.00**	0.00**	1.00	0.33	0.12	0.97	0.00**
2, 3	0.10	0.93	0.00**	0.00**	1.00	0.00**	0.00**
2,4	0.06	0.98	0.00**	0.00**	1.00	0.03*	0.00**
2,5	0.02*	0.07	0.00**	0.00**	0.55	0.12	0.02*
3,4	0.99	0.54	1.00	0.72	1.00	0.75	0.36
3, 5	0.90	0.18	1.00	0.07	0.40	0.37	0.00**
4, 5	0.99	0.00**	1.00	0.64	0.46	0.97	0.01**

## Tukey HSD Tests for Each *Content of the Lesson* Question for Each Class Section Pair (p-values)

<sup>±</sup>Numbers correspond to the same class sections as defined in table 10.

\*Significant at the 95% level of confidence

\*\*Significant at the 99% level of confidence

the individual sessions rated between 6.0 and 7.0 (the high end of the scale). There were, however, 8 questions for which the laboratory section rated between 4.0 and 5.2 (the mid-to-high end of the middle of the scale), including four *implementation of the lesson* questions (Table 8), two *content of the lesson* questions (Table 10), and two *classroom culture* questions (Table 12). This suggests that inquiry-based approaches were present to some degree in the laboratory section. However, mean ratings between 1.0 and 3.4 (the low to low-middle end of the scale) were observed for 11 of the 21 questions, including three *implementation of the lesson* questions (Table 8), five *content of the lesson* questions (Table 8), five *content of the lesson* questions (Table 10), and three *classroom culture* questions (Table 12). A mean

Active participation of students' encouraged	Teacher's respect for students' ideas	Students' respect for other students' ideas	Students encouraged to generate ideas	Student- student collaborative relationships	Teacher- student collaborative relationships
0.53	0.47	0.20	0.26	0.31	0.79
0.01**	0.00**	0.00**	0.03*	0.00**	0.00**
0.01*	0.31	0.00**	0.65	0.00**	0.00**
0.00**	0.00**	0.00**	0.01**	0.00**	0.00**
0.69	0.48	0.70	0.00**	0.13	0.00**
0.53	1.00	0.16	0.04*	0.04*	0.00**
0.34	0.07	0.01**	0.00**	0.09	0.00**
0.99	0.44	0.74	0.59	0.95	0.88
0.94	0.65	0.06	0.96	0.99	0.96
0.99	0.05*	0.53	0.27	0.99	0.99
	Active participation of students' encouraged 0.53 0.01** 0.00** 0.69 0.53 0.34 0.99 0.94 0.99	Active participation of students' encouragedTeacher's respect for students' ideas0.530.470.01**0.00**0.01*0.310.00**0.00**0.690.480.531.000.340.070.990.440.940.650.990.05*	Active participation of students' encouragedTeacher's respect for students' ideasStudents' respect for other students' ideas $0.53$ $0.47$ $0.20$ $0.01^{**}$ $0.00^{**}$ $0.00^{**}$ $0.01^{*}$ $0.31$ $0.00^{**}$ $0.00^{**}$ $0.00^{**}$ $0.00^{**}$ $0.00^{**}$ $0.00^{**}$ $0.00^{**}$ $0.53$ $1.00$ $0.16$ $0.34$ $0.07$ $0.01^{**}$ $0.99$ $0.44$ $0.74$ $0.94$ $0.65$ $0.06$ $0.99$ $0.05^{*}$ $0.53$	Active participation of students' encouragedTeacher's respect for students' ideasStudents' respect for other students' ideasStudents encouraged to generate ideas $0.53$ $0.47$ $0.20$ $0.26$ $0.01^{**}$ $0.00^{**}$ $0.00^{**}$ $0.03^{*}$ $0.01^{**}$ $0.00^{**}$ $0.00^{**}$ $0.03^{*}$ $0.01^{*}$ $0.31$ $0.00^{**}$ $0.65$ $0.00^{**}$ $0.00^{**}$ $0.00^{**}$ $0.01^{**}$ $0.69$ $0.48$ $0.70$ $0.00^{**}$ $0.53$ $1.00$ $0.16$ $0.04^{*}$ $0.34$ $0.07$ $0.01^{**}$ $0.00^{**}$ $0.99$ $0.44$ $0.74$ $0.59$ $0.94$ $0.65$ $0.06$ $0.96$ $0.99$ $0.05^{*}$ $0.53$ $0.27$	$\begin{array}{c c c c c c c c c c c c c c c c c c c $

### Tukey HSD Tests for Each *Classroom Culture* Question for Each Class Section Pair (p-values)

<sup>±</sup>Numbers correspond to the same class section groups as defined in table 12.

\*Significant at the 95% level of confidence

\*\*Significant at the 99% level of confidence

rating of 1.0 was even observed for four *content of the lesson* questions (Table 10) and for one *implementation of the lesson* question (Table 8). Those clusters at the low end of the rating scale provide additional evidence that the laboratory section was traditionally-based.

Statistically significant differences between the lecture section and the laboratory section were not observed for any of the *classroom culture* questions (Table 20). Statistically significant differences between the lecture section and laboratory section were observed for two *implementation of the lesson* questions (Table 18). A lower mean rating for the question related to instructor confidence was observed for the laboratory

section (Table 8). This was to be expected, given that the laboratory portion of the course was taught by a graduate student assistant who had very little background and experience with meteorology. A higher mean rating for the question related to student-student interaction was observed for the laboratory section (Table 8). This was also to be expected, given that the laboratory portion of the course is where investigative processes are most likely to take place. However, the mean rating for the lecture section was 4.2, indicating that interactions between students were not fully consistent with the national and state teaching standards. Overall, these findings provide additional evidence that the lecture and laboratory sections were taught with similar consistency relative to the national and state standards with regard to the *implementation of the lesson* and *classroom culture* components.

Statistically significant differences between the lecture and laboratory sections were observed for five *content of the lesson* questions, including the questions related to the portrayal of subject matter, instructor competence, connection to other subjects, application to the real world, and the use of abstractions (Table 19). With the exception of the question related to the portrayal of subject matter, the highest mean ratings were observed for the lecture section. Overall, these findings provide additional evidence that, for the *content of the lesson* component, the lecture section was more consistent with national and state standards than was the laboratory section.

*The Geography 1900 Class Sections.* For the Geography 1900b section taught by "Instructor 1," mean ratings between 4.8 and 5.0 (the high end of the middle of the scale) were observed for the four "overall" ratings (Tables 7, 9, 11, and 13). For the Geography 1900d section taught by "Instructor 2," mean ratings between 4.4 and 5.3 were observed for the four "overall" ratings (Tables 7, 9, 11, and 13). No statistically significant differences between the section taught by "Instructor 1" and the section taught by "Instructor 2" were observed for the "overall" ratings. These findings suggest that Geography 1900 had at least partial consistency with the inquiry-based national and state

standards. For all three lesson components, both instructors taught with similar consistency relative to the national and state standards.

For the Geography 1900b section taught by "Instructor 1," there were three questions which rated between 6.0 and 7.0 (the high end of the scale), two of which were content of the lesson questions related to instructor competence and the use of abstractions (Table 10), and one of which was an *implementation of the lesson* question related to the pace of the lesson (Table 8). The instructor therefore "had an adequate grasp of the lesson concepts to help facilitate learning without giving or expecting 'canned' answers or solutions" (Science and Mathematics Program Improvement, 2003a; p. 7); conducted the instruction in a way that the concepts were put into "larger contexts, such as more general theories of scientific laws" (Science and Mathematics Program Improvement, 2003a; p. 8); and gave adequate time for students "to complete tasks and converse about their work" (Science and Mathematics Program Improvement; 2003a, p. 5). In addition, mean ratings between 4.6 and 5.4 (the high end of the middle of the scale) were observed for 13 of the 20 questions, including five *implementation of the lesson* questions (Table 8), two *content of the lesson* questions (Table 10), and the six *classroom culture* questions (Table 12). These findings provide additional evidence that the Geography 1900b section taught by "Instructor 1" had at least partial consistency with the inquiry-based national and state standards, especially with regard to the competency of the instructor, the use of abstractions, and the pace of the lesson.

For the Geography 1900d section taught by "Instructor 2," there were three *classroom culture* questions which rated between 5.7 and 5.9 (near the high end of the scale), including the questions related to active participation of students' encouraged, students' respect for other students' ideas, and teacher-student collaborative relationships (Table 12). The classroom environment was therefore such that the instructor made "specific efforts...to engage all students, including connecting their prior experiences, interests, and personal lives" (Science and Mathematics Program Improvement, 2003a; p.

8); students "accepted each other's ideas without ridicule... [and attempted] to understand others' reasoning" (Science and Mathematics Program Improvement, 2003a; p. 9); and the instructor and students worked together "to solve problems and seek answers to questions" (Science and Mathematics Program Improvement; 2003a, p. 9). Additionally, the highest mean rating of 7.0 was observed for the *content of the lesson* question related to instructor competence. All but two of the mean values for the remaining 16 questions were observed to range between 3.3 and 5.4 (the middle of scale), including the seven *implementation of the lesson* questions (Table 8), four *content of the lesson* questions (Table 10), and three *classroom culture* questions (Table 12). These results provide additional evidence that the Geography 1900 section taught by "Instructor 2" had at least partial consistency with the inquiry-based national and state standards, especially with regard to the *classroom culture* and the competency of the instructor.

A statistically significant difference between the Geography 1900b section taught by "Instructor 1" and the Geography 1900d section taught by "Instructor 2" was observed only for the question related to the pace of the lesson (Table 18), for which a high value of 6.0 was observed for "Instructor 1" and a middle value of 4.0 was observed for "Instructor 2" (Table 8). These findings provide additional evidence that, with the exception of the pace, both instructors taught the Geography 1900 sections in a similar manner of consistency to national and state standards.

Statistically significant differences between the Geography 1900b section taught by "Instructor 1" and the Geography 1050b lecture section were observed for the four "overall" ratings (Tables 14, 15, 16, and 17). Statistically significant differences between the Geography 1900b section taught by "Instructor 1" and the Geography 1050b laboratory section were observed for each "overall" rating except *classroom culture* (Tables 14, 15, 16, and 17). Statistically significant differences between the Geography 1900b section taught by "Instructor 2" and the Geography 1050b lecture section were observed for each "overall" rating except *classroom* culture section were

17). Statistically significant differences between the Geography 1900d section taught by "Instructor 2" and the Geography 1050b laboratory section were observed for each "overall" rating except *implementation of the lesson* (Tables 14, 15, 16, and 17). In all cases for which statistically significant differences were observed, the higher mean ratings were obtained in the Geography 1900 sections (Tables 7, 9, 11, and 13). These findings provide evidence that the inquiry-based sections were taught with a greater consistency to national and state teaching standards as well as inquiry-based investigative approaches to instruction and learning when compared with the Geography 1050b lecture and laboratory sections.

As for the seven *implementation of the lesson* questions, statistically significant differences between the Geography 1050b lecture section and the Geography 1900b classes taught by "Instructor 1" were observed for each question except the one related to the wrap-up of the lesson (Table 18). Statistically significant differences between the Geography 1050b lecture section and the Geography 1900d course taught by "Instructor 2" were observed for four *implementation of the lesson* questions, including the questions related to instructor confidence, classroom management, student-student interaction, and reflection on the lesson (Table 18). Statistically significant differences between the Geography 1050b laboratory section and the Geography 1900b section taught by "Instructor 1" were observed for the *implementation of the lesson* questions related to the pace of the lesson and the wrap-up of the lesson (Table 18). No statistically significant differences between the Geography 1050b laboratory section and the Geography 1900d classes taught by "Instructor 2" were observed for the implementation of the lesson questions (Table 18). In almost all cases where there were significant differences between the class section pairs, the higher mean ratings were observed in the inquirybased sections (Table 8). The only exception was a higher instructor confidence rating for the Geography 1050b lecture section than for either of the Geography 1900 sections (Table 8). These findings provide additional evidence that the inquiry-based sections

were taught with a greater consistency to meet the inquiry-based national and state teaching standards than was the Geography 1050b lecture section, as evidenced in the *implementation of the lesson* component. However, there is not enough evidence to suggest that the inquiry-based class sections were taught with a greater consistency relative to the national and state teaching standards than was the Geography 1050b laboratory section with regard to the *implementation of the lesson* component. There is considerable similarity between the observed data for each of them.

As for individual *content of the lesson* questions, statistically significant differences between the Geography 1050b lecture section and the Geography 1900b section taught by "Instructor 1" were observed for the majority of the questions, including the questions related to the intellectual engagement of students, the portrayal of subject matter, connection to other lessons, and connection to other subjects (Table 19). Statistically significant differences between the Geography 1050b lecture section and the Geography 1900d section taught by "Instructor 2" were observed for the same four questions (Table 19). Statistically significant differences between the Geography 1050b laboratory section and the Geography 1900b section taught by "Instructor 1" were observed for the majority of the *content of the lesson* questions, including the questions related to instructor competence, connection to other lessons, application to the real world, and the use of abstractions" (Table 19). Statistically significant differences between the Geography 1050b laboratory section and the Geography 1900d section taught by "Instructor 2" were observed for the same four questions (Table 19). In almost all cases where there were statistically significant differences, the higher mean ratings were observed for the inquiry-based sections (Table 10). The only exception was a higher rating for the question related to connection to other subjects for the Geography 1050b lecture section than for either of the Geography 1900 sections (Table 10). Overall, these findings provide additional evidence that the inquiry-based sections were taught with greater consistency relative to the national and state teaching standards and inquiry-

based investigative approaches to instruction and learning than were the Geography 1050b lecture and laboratory section, as observed for the *content of the lesson* component.

As for individual *classroom culture* questions, statistically significant differences between the Geography 1050b lecture section and the Geography 1900b section taught by "Instructor 1" were observed for all six questions (Table 20). Statistically significant differences between the Geography 1050b lecture section and the Geography 1900d section taught by "Instructor 2" were observed for the *classroom culture* questions except the two related to teacher's respect for students' ideas and students encouraged to generate ideas (Table 20). Statistically significant differences between the Geography 1050b laboratory section and the Geography 1900b section taught by "Instructor 1" were observed for the *classroom culture* questions related to students encouraged to generate ideas and teacher-student collaborative relationships (Table 20). Statistically significant differences between the Geography 1050b laboratory section and the Geography 1900d section taught by "Instructor 2" were observed for the *classroom culture* questions related to students encouraged to generate ideas, student-student collaborative relationships and teacher-student collaborative relationships (Table 20). In all cases where there were significant differences, the higher mean ratings were observed in the inquiry-based Geography 1900 sections (Table 12). These findings provide additional evidence that the Geography 1900 sections were taught by both instructors with a greater consistency relative to national and state teaching standards and inquiry-based investigative approaches to instruction and learning than were the Geography 1050b lecture section with regard to the *classroom culture* component. These findings also provide additional evidence that the Geography 1900 sections were taught with a greater consistency to national and state standards than the Geography 1050b laboratory section, but that this greater consistency was mostly concentrated in the areas with regard to students encouraged to generate ideas and teacher-student collaborative relationships. There was

a greater emphasis on a "trusting, risk-taking atmosphere" (Science and Mathematics Program Improvement, 2003a; p. 9) and on teachers and students working together "to solve problems and to seek answers to questions" (Science and Mathematics Program Improvement, 2003a; p. 9) in the Geography 1900 sections than in the Geography 1050 laboratory section.

*The Geosciences 2900 Class Section.* For the Geosciences 2900 section taught by "Instructor 2," mean ratings between 4.1 and 5.3 (the high end of the middle of the scale) were observed for the "overall" ratings except *classroom culture*, for which a mean rating of 5.9 (the high end of the scale) was observed (Tables 14, 15, 16, and 17). No statistically significant differences between the Geosciences 2900 section taught by "Instructor 2" and the Geography 1900 sections taught by either of the instructors ("1" or "2") were observed for the "overall" ratings (Tables 14, 15, 16, and 17). These findings suggest that the Geosciences 2900 and Geography 1900 class sections were taught with a similar manner of consistency to the inquiry-based national and state standards, and that "Instructor 2" taught both the Geography 1900 class section and the Geosciences 2900 class section in a similar manner of consistency to the national and state standards.

For the Geosciences 2900 section, eight questions rated between 5.6 and 7.0 (the high end of the scale), one of which was an *implementation of the lesson* question related to instructor confidence (Table 8); three of which were *content of the lesson* questions related to the intellectual engagement of students, the portrayal of subject matter, and instructor competence (Table 10); and four of which were *classroom culture* questions related to the active participation of students encouraged, teacher's respect for students' ideas, students' respect for other students' ideas, and student-student collaborative relationships (Table 12). To a high degree, therefore, the instructor was "knowledgeable about the topic of the lesson and [was] able to respond to student questions" (Science and Mathematics Program Improvement; 2003a, p. 5); students sought "answers to important questions... [gathered] appropriate information to address them...and [discussed their

findings] with other students and the teacher" (Science and Mathematics Program Improvement; 2003a, p. 5); tasks and activities were "complex and open-ended" (Science and Mathematics Program Improvement, 2003a; p. 7); the instructor had an "adequate grasp of the lesson concepts to help facilitate learning without giving or expecting 'canned' answers or solutions" (Science and Mathematics Program Improvement, 2003a; p. 7); students were "actively engaged in activities and tasks" (Science and Mathematics Program Improvement, 2003a; p. 8); the instructor accepted "ideas without making judgments or until there [was] more discussion" (Science and Mathematics Program Improvement, 2003a; p. 8); students "accepted each other's ideas without ridicule... [and attempted] to understand others' reasoning" (Science and Mathematics Program Improvement, 2003a; p. 9); and students' interactions and discussions were constructive and contributed "to task completion and improved understanding" (Science and Mathematics Program Improvement, 2003a; p. 9). The highest possible mean rating of 7.0 was observed for the questions related to instructor confidence, instructor competence, and students' respect for other students' ideas. For the questions that did not receive high ratings, mean ratings between 4.0 and 5.4 (the high end of the middle of the scale) were observed for the *implementation of the lesson* and *classroom culture* questions (Tables 8 and 12), and mean rating between 1.4 and 3.0 (the low to low-middle end of the scale) were observed for the *content of the lesson* questions (Table 10). There were therefore some aspects of the content of the lesson component for which Geosciences 2900 was not consistent with the national and state standards, and there were some aspects of the *implementation of the lesson* and *classroom culture* components for which Geosciences 2900 was only partially consistent with the national and state standards. Nevertheless, these findings suggest that inquiry-based approaches were present to a high degree in the Geography 2900 section for several areas that were examined by the SAMPI Lesson Observation System.

Statistically significant differences between the Geography 2900 section taught by "Instructor 2" and the Geography 1900b section taught by "Instructor 1" were observed for two *implementation of the lesson* questions related to instructor confidence and the pace of the lesson (Table 18), and for the *content of the lesson* question related to the use of abstractions (Table 19). Statistically significant differences between the Geography 2900 section taught by "Instructor 2" and the Geography 1900d section taught by "Instructor 2" were observed for two *implementation of the lesson* questions related to instructor confidence and teacher-student interaction (Table 18), two content of the lesson questions related to the portrayal of subject matter and the use of abstractions (Table 19) and the *classroom culture* question related to teacher's respect for students' ideas (Table 19). Except for the question related to the use of abstractions, the higher mean ratings were observed for the Geosciences 2900 section (Tables 8, 10, and 12). Of the eight questions for which mean ratings between 5.6 and 7.0 were observed for the Geosciences 2900 section, the mean rating for the question related to instructor confidence was statistically significant in terms of being higher than what was observed for the Geography 1900b section taught by "Instructor 1;" and the mean ratings for the questions related to instructor confidence, the portrayal of subject matter, and teacher's respect for students' ideas were statistically significant in terms of being higher than what was observed for Geography 1900d section taught by "Instructor 2" (Tables 18, 19, and 20). These findings provide additional evidence that the Geosciences 2900 and Geography 1900 class sections were taught with consistency relative to the inquiry-based national and state standards, and that "Instructor 2" taught both the Geography 1900d section and the Geosciences 2900 section with similar consistency.

Statistically significant differences between the Geosciences 2900 section and the Geography 1050b lecture section taught by "Instructor 1" were observed for the "overall" ratings except *content of the lesson* (Tables 14, 15, 16, and 17). Statistically significant differences between the Geosciences 2900 section and the Geography 1050b laboratory

section were observed for the four "overall" ratings (Tables 14, 15, 16, and 17). In all cases for which significant differences were observed, the higher mean ratings were in the inquiry-based Geosciences 2900 section (Tables 7, 9, 11, and 13). Except for the *content of the lesson* component, these findings suggest that the Geosciences 2900 section were taught with greater consistency relative to the inquiry-based national and state standards than were the Geography 1050b lecture and laboratory section. For the *content of the lesson* component, the inquiry-based Geosciences 2900 section and the Geography 1050b lecture section were taught with similar consistency relative to the standards.

Statistically significant differences between the Geosciences 2900 section and the Geography 1050b lecture section were observed for the implementation of the lesson questions except those related to the pace of the lesson and the wrap-up of the lesson (Table 18); for three *content of the lesson* questions related to intellectual engagement of students, the portrayal of subject matter, and the use of abstractions (Table 19); and for the six *classroom culture* questions (Table 20). For all of these cases except the use of abstraction, the higher mean ratings were observed for the Geosciences 2900 section (Tables 8, 10, and 12). Statistically significant differences between the Geosciences 2900 section and the Geography 1050b laboratory section were observed for the majority of the *implementation of the lesson* questions including those related to instructor confidence, teacher-student interaction, reflection on the lesson, and the wrap-up of the lesson (Table 18); for the majority of the *content of the lesson* questions including those related to instructor confidence, connection to other lessons, intellectual engagement of students, and the use of abstractions (Table 19); and for half of the *classroom culture* question including those related to students' respect for other students' ideas, students encouraged to generate ideas, and student-student collaborative relationships (Table 20). For all of these cases, the higher mean ratings were observed for the Geosciences 2900 section (Tables 8, 10, and 12). These findings provide additional evidence that, except

for the *content of the lesson* component, the Geography 2900 section was taught with greater consistency relative to inquiry-based national and state standards than were the Geography 1050b lecture and laboratory sections. For the *content of the lesson* component, there was a similar degree of consistency between the Geosciences 2900 section and the Geography 1050b lecture section for the majority of question, and one question revealed a higher mean value for the Geography 1050b lecture section.

*Summary for All Class Sections.* For Geography 1050b, low to low-middle mean ratings were observed for the majority of the 21 questions for both the lecture and laboratory sections. Low-middle mean values were also observed for the "overall" ratings for both the lecture and laboratory sections except *content of the lesson*, for which a middle rating of 4.1 was observed for the lecture section. The "overall" *content of the lesson* rating of 4.1 for the lecture section suggests that this section had at least some degree of consistency relative to national and state standards with regard to the *content of the lesson* indicator questions were analyzed for the lecture section, it was revealed that mean ratings higher than 2.6 were only obtained for the two questions related to instructor competence (7.0) and the use of abstractions (5.4). These findings provide evidence that Geography 1050b was more traditional than inquiry-based with regard to the national and state standards.

For the Geography 1900 sections, mean ratings at the high end of the middle of the scale were observed for the "overall" ratings for both instructors, and for the majority of the 21 questions for both instructors. For the section taught by "Instructor 1," there were three questions which rated on the high end of the scale, two of which were *content of the lesson* questions and one of which was an *implementation of the lesson* question. For the section taught by "Instructor 2," there were three questions which rated near the high end of the scale, all of which were *classroom culture* questions. Lower mean ratings were observed for the remaining questions. This suggests that the Geography 1900 sections were not fully consistent with the inquiry-based national and state standards.

The findings of the "Item analysis" reported in this chapter revealed that there were no significant increases in the number of correct responses from pre- to posttest for any of the application questions. It was suggested that Geography 1900 was not developing problem solving skills as intended in the inquiry course design. Students were not able to apply the processes of science on paper and pencil examinations. The reason for this appears in the analysis of the classroom observations. Inquiry was taking place to some extent, but apparently not to the degree necessary to bring about changes in students' understandings beyond the comprehension level.

For Geosciences 2900, there were eight questions and one "overall" rating at or very near the high end of the scale. This provides evidence that that inquiry-based approaches were present to a high degree in the Geography 2900 section. The findings of the "Item analysis" reported in this chapter revealed that the only question observed for which a significant pre- to posttest increase in the number of student correct responses occurred was an application question. The success that students had with this question suggested that Geosciences 2900 was effective in teaching the multiple concepts and processes necessary to answer this question correctly. This, therefore, provided evidence that inquiry was being at least partially applied in this particular inquiry-based section. The analysis of the classroom observations supports this finding. Even though the mean ratings were within or near the middle of the scale for the majority of the SAMPI Lesson Observation questions, there were eight question for which high mean ratings were observed. The mean ratings for these questions were consistently higher than the mean ratings that were observed for the Geography 1900 sections, but the gains were not statistically significant for most of the questions.

The fact that inquiry was only partially taking place within the Geography 1900 and Geosciences 2900 section appears to result from the design of the courses. The statistical tests demonstrated that "Instructor 1" and "Instructor 2" taught the inquirybased sections with a similar consistency relative to the national and state standards.

There were, however, examples wherein one section received a significantly higher rating on the SAMPI instrument than the other section. The two most noteworthy examples of this were for the *implementation of the lesson* questions related to the pace of the lesson and instructor confidence. For the pace of the lesson, the mean rating for the Geography 1900 class section taught by "Instructor 1" was 6.0 (Table 8), while the mean rating for both the Geography 1900 and Geosciences 2900 class sections taught by "Instructor 2" was 4.0 (Table 8). This suggests that the pace used by "Instructor 1" was more consistent with the inquiry-based national and state standards than the pace used by "Instructor 2." For instructor confidence, the mean rating for the Geosciences 2900 course taught by "Instructor 2" was the highest possible rating of 7.0 (Table 8), while the mean rating for both the Geography 1900 class section taught by "Instructor 1" and the Geography 1900 class section taught by "Instructor 2" was 5.0 (Table 8). Therefore, it was only during the Geosciences 2900 section that "Instructor 2" demonstrated a high level of confidence.

There were at least three patterns that were common to all of the class sections.

First, the *content of the lesson* question related to the importance of the content rated at the highest possible value of 7 for all 39 class section. This provides evidence that the lessons assigned for all of the class sections did not "focus on trivial or minor concepts" (Science and Mathematics Program Improvement; 2003a, p. 7).

Second, for the *content of the lesson* question related to connection to other subjects, low mean ratings between 1.0 and 2.0 were observed for all classroom sections, with the lowest possible mean rating of 1.0 being observed for the Geography 1900 class sections taught by both instructors, and for the Geography 1050b laboratory section. Connections "between the key ideas and processes of the current lesson and previous or future science units/topics" (Science and Mathematics Program Improvement; 2003a, p. 7) were therefore not made within *any* of the courses. Instructors did not discuss or ask questions about "how the core ideas of the current lesson relate to previous or future science unit/topics" (Science and Mathematics Program Improvement; 2003a, p. 7), and

students did not use class time to "identify and/or discuss connections" (Science and Mathematics Program Improvement; 2003a, p. 7).

Third, the *content of the lesson* question related to instructor competence rated at the highest possible value of 7 for all class sections *except* for the Geography 1050b laboratory section taught by a graduate student assistant. This provides evidence that information related to important concepts was presented by all primary instructors in ways that were "accurate" (Science and Mathematics Program Improvement; 2003a, p. 7), and that questions asked by all primary instructors challenged students "to think more deeply rather than simply recite facts or 'canned' answers" (Science and Mathematics Program Improvement; 2003a, p. 7).

The lower mean instructor competence rating for the Geography 1050b laboratory section was not entirely unexpected, given that the laboratory portion of the course was taught by a graduate student assistant. Through a personal interview with the graduate student, the researcher learned that the graduate student was an expert in the field of soils, but had very little background and experience with meteorology. This may have been a hindrance to the graduate student. However, the mean instructor competence rating for the Geography 1050b laboratory sessions was on the high end of the middle of the scale (5.2). This suggests that even though this graduate student may have asked questions that were not as challenging as they could have been, the meteorology content was presented in a competent manner.

There were three other *content of the lesson* questions and one *implementation of the lesson* question for which the Geography 1050b laboratory section received statistically significant lower mean ratings than what was observed for the Geography 1050b lecture section. This provides more evidence that the graduate student's lack of background in meteorology may have been a hindrance, especially with regard to the content component. However, there was also one *implementation of the lesson* question related to student-student interaction and one *content of the lesson* question related to the

portrayal of subject matter for which the Geography 1050b laboratory section received statistically significant higher ratings than the Geography 1050b lecture section. The mean ratings for both of these questions were on the low end of the scale for the lecture section (near 2.0), but near the middle of the scale for the laboratory section (near 4.0). It therefore appears that the graduate student made use of methods that were consistent with the national and state standards. This is explained by the instructional structure in which students in the Geography 1050b laboratory section worked in groups that were "organized and arranged so that there [was] appropriate and substantive student interactions that [led] to improved understanding of concepts and development of skills," (Science and Mathematics Program Improvement; 2003a, p. 5), and that these groups engaged in tasks and activities that were "complex and open-ended" (Science and Mathematics Program Improvement, 2003a; p. 7).

## Analysis of the Geography 1050 "Modules"

The interpretation of the classroom observations suggests that, overall, the Geography 1050b lecture section was more traditional than inquiry-based. However, there were two lecture sessions for which the instructor implemented non-traditional activities that were referred to as *Flexible Teaching Modules for Physical Geography*. These modules, "Campus Thermal" and "Blown Away," were designed through the cooperation of the Geography 1050 instructor and another physical geography instructor. Through a personal interview with both of these instructors, the researcher learned that the modules were designed to be inquiry-based.

"Campus Thermal" was taught on January 24, 2005. All students were asked to get into groups of four. A map of Western Michigan University was displayed on a large screen at the front of the lecture hall. The instructor stated that temperature data were collected from various locations on campus. Nine pictures that highlighted these locations were displayed, and groups were asked to answer several questions about these

pictures. One question that students were asked to answer, for example, was, "Which location has the highest albedo, and why?" The instructor walked around the lecture hall while students discussed the problems presented within their groups. The students were called to attention about halfway through the session. Individual groups were asked to present responses, and class-wide discussions about these responses followed. Some of the questions did not have definitive answers. The instructor explored the reasoning processes employed by the students to generate responses. The instructor at various times even made comments like "I am interested in your reasoning" and "I don't know the answer because I didn't measure it. But we can make reasonable deductions. That's science."

"Blown Away" was taught on February 7, 2005. All students were asked to get into groups of three. A sheet was handed out that contained information about the Beufort wind scale. Included on this sheet was information about how a house is affected when it is hit with winds of various strengths, and how waves on bodies of water are affected by wind speeds. A series of ten video clips were shown on a large screen at the front of the lecture hall. Three of these videos showed waves on bodies of water, three showed flags waving in the wind, and four showed trees swaying in the wind. The groups were asked to use the hand-out to identify the number on the Beufort wind scale represented by each video. The instructor also asked the groups to generate responses to a series of questions. One question that students were asked to answer, for example, was "What is the physically fastest speed that a sailboat can travel?" As with the previous module, the instructor was primarily interested in students' reasoning processes. The students were called to attention about two-thirds of the way through the session. As with the previous module, individual groups were asked to present responses, and classwide discussions about these responses followed.

In order to examine whether the modules were inquiry-based as defined by state and national standards, the SAMPI Lesson Observation System ratings were examined

for both sessions for which the modules were used. The ratings for the seven *implementation of the lesson* questions and the "overall" *implementation of the lesson* rating for both module sessions are in Table 21. The ratings for seven of the eight *content of the lesson* questions and the "overall" *content of the lesson* rating for both module sessions are in Table 22. The ratings for the six *classroom culture* questions, the "overall" *classroom culture* rating, and the "overall" *summary* rating for both module sessions are in Table 23.

For the "Campus Thermal" module, a high value of 6 was observed for the "overall" ratings except *content of the lesson*, for which a high-middle value of 5 was observed. In addition, high ratings of 6 or 7 were observed for 14 of the 20 SAMPI instrument questions, including six *implementation of the lesson* questions, three *content of the lesson* questions, and five *classroom culture* questions. A high-middle rating of 5 was observed for the *implementation of the lesson* question related to teacher-student interaction, for the *content of the lesson* questions related to the portrayal of subject matter and application to the real world, and for the *classroom culture* question related to student-student collaborative relationships. A low rating of 2 was observed for the *content of the lesson* questions related to other lessons and connection to other subjects.

For the "Blown Away" module, a high value of 6 was observed for the "overall" ratings except *content of the lesson*, for which a value of 5 was observed. In addition, high ratings of 6 or 7 were observed for 11 of the 20 instrument questions, including the seven *implementation of the lesson* questions, four *content of the lesson* questions, and four *classroom culture* questions. A high-middle rating of 5 was observed for four *implementation of the lesson* questions, one *content of the lesson* question related to application to the real world, and one *classroom culture* questions related to teacher's respect for students' ideas. A middle rating of 4 was observed for the *classroom culture* 

Implementation Question	"Campus Thermal"	"Blown Away"
Instructor confidence	7	7
Teacher-student interaction	5	5
Classroom management	6	5
Pace of the lesson	7	7
Student-student interaction	6	6
Reflection on the lesson	7	5
Wrap-up of the lesson	7	5
Overall implementation rating	6	6

## Ratings for Each Implementation of the Lesson Question for the Geography 1050 Module Sessions

## Table 22

# Ratings for Each *Content of the Lesson* Question for the Geography 1050 Module Sessions

Content Question	"Campus Thermal"	"Blown Away"
Intellectual engagement of students	6	6
Portrayal of subject matter	5	6
Instructor competence	7	7
Connection to other lessons	2	2
Connection to other subjects	2	2
Application to the real world	5	5
Use of abstractions	7	7
Overall content rating	5	5

Culture Question	"Campus Thermal"	"Blown Away"
Active participation of students encouraged	7	7
Teacher's respect for students' ideas	7	5
Students' respect for other students' ideas	7	7
Students encouraged to generate ideas	7	6
Teacher-student collaborative relationships	7	6
Student-student collaborative relationships	5	4
Overall culture rating	6	6
Overall summary rating	6	6

## Ratings for Each *Classroom Culture* Question and the "Overall" *Summary* Rating for the Geography 1050 Module Sessions

question related to student-student collaborative relationships. Similar to what was observed for the "Campus Thermal" module, a low rating of 2 was observed for the two *content of the lesson* questions related to connection to other lessons and connection to other subjects.

These observations provide evidence that the two Geography 1050 modules were indeed taught with a high degree of consistency to the inquiry-based national and state standards, especially with regard to the *implementation of the lesson* and *classroom culture* components. It is therefore noteworthy that even though the Geography 1050 course was taught in a traditional manner *overall*, the instructor made an effective use of inquiry-based teaching strategies through the *Flexible Teaching Modules for Physical Geography*.

## Observer Reliability Analysis

For the purpose of classroom observation data reliability, a second person was hired to observe the same sections and to record data. Simultaneous observations were made for three Geography 1050b lecture sessions, three Geography 1050b laboratory sessions, three Geography 1900b class sessions, three Geography 1900d class sessions, and three Geosciences 2900 class sessions. Similar to the researcher, the second observer focused on the pedagogy employed by the instructor, the interactions among the students, and the interactions between the teacher and the students. At least one observation was required per minute, although several observations per minute were usually made. The researcher and the second observer sat at opposite sides of the classroom and had no communication with each other. All recorded observations made by the second observer were word processed and coded by the researcher using the SAMPI Lesson Observation System.

The overall reliability of the researcher's observations was verified by comparing the ratings assigned to the observations made by the second observer with the ratings assigned to the observations made by the researcher for the same class sessions. Based on guidelines presented during the training sessions for the SAMPI Lesson Observation System, an individual rating was considered to be reliable if the absolute value of the differences between that rating and a co-rating was less than 2. As an example, for the question related to teacher-student interaction, a rating of 2 was assigned for the researcher's observations of the Geography 1050 lecture session taught on January 21, 2005, while a rating of 3 assigned for the second observer's record of the same class session. The absolute value of the difference between these values was less than 2:

|2 - 3| = 1

The rating assigned for the question related to teacher-student interaction was therefore considered to be reliable.

Based on guidelines presented during the training sessions for the SAMPI Lesson Observation System, the observations for a particular class session were considered to be reliable if *most* of the absolute values of the differences between the co-ratings for the four "overall" ratings and for the 21 questions were less than 2. It was acceptable for there to be an occasional pair for which the absolute value of the difference was 2 or more. If, however there were several pairs for which the absolute value of the difference was 2 or more, this suggested that the observations made by the researcher did not provide an authentic picture of what was taking place within that particular session. There were no specific criteria for the maximum number of pairs that could be considered "occasional."

All pairs and absolute values of the differences between the co-ratings are in tables in Appendix K. In these tables, classroom observer "1" refers to the researcher and classroom observer "2" refers the second person who was hired to record observations.

There were no "overall" pairs for which the absolute value of the difference was 2 or more. For the 21 questions, there were 9 pairs for which the absolute value of the difference was 2 or more. This was only 3% of the total number of pairs. There were no class sessions judged by the researcher to have possessed more than an "occasional" corater difference of 2 or more. The overall reliability of the researcher's observations was established. It was concluded that the observations made by the researcher did indeed provide an authentic picture of what was taking place within the classrooms.

## Rater Reliability Analysis

For the purpose of inter-rater reliability, the Director of the Science and Mathematics Program Improvement (SAMPI) agreed to read through and code the handwritten observations for two sessions observed by the researcher and one session

observed by the second observer for each of the following class sections: Geography 1900b, Geography 1900d, Geosciences 2900, the lecture section for Geography 1050b, and the laboratory section for Geography 1050b.

The overall reliability of the ratings assigned by the researcher was verified by comparing the ratings assigned by the Director of SAMPI with the ratings assigned by the researcher for the same class sessions. Similar to the inter-observer reliability analysis, the ratings assigned by the researcher for a particular class session were considered to be reliable if *most* of the absolute values of the differences between the co-ratings for the four "overall" ratings and for the 21 questions were less than 2.

All pairs and absolute values of the differences between the co-ratings are in tables in Appendix L. In these tables, classroom observer "1" refers to the researcher, classroom observer "2" refers the second person who was hired to record observations, observation coder "a" refers to the researcher, and observation coder "b" refers to the Director of SAMPI who read through and coded the hand-written classroom observations.

There was one "overall" pair for which the absolute value of the difference was 2 or more. This was for the "overall" *classroom culture* rating for the March 9, 2005 session of Geography 1900d. An overall rating of 6 was assigned by the primary researcher, while an "overall" rating of 4 was assigned by the Director of SAMPI. For the 21 questions, there were 23 pairs for which the absolute value of the difference was 2 or more. This was 7% of the total number of pairs. There was one class session judged by the researcher to have possessed more than an "occasional" co-rater difference of 2 or more. This was for the March 9, 2005 session of Geography 1900d, the same class section for which a co-rater difference of 2 or more was determined for the "overall" culture rating. For this class session, there were 9 questions for which a co-rater difference of 2 or more was observed. The observed reliability of the researcher's ratings was not established for this class session. However, the overall reliability of the

researcher's observations was acceptable. Excluding the March 9, 2005 session of Geography 1900d, the absolute value of the difference for all of the "overall" ratings and for all but 14 (5%) of the co-rater pairs for the questions was less than 2. It was concluded that the ratings assigned by the researcher did indeed provide an authentic picture of what was taking place within the classroom.

## Interviews

A total of 30 students from the sample initially agreed to be interviewed. Twentyfour of them, or 14% of the entire population, followed through and reported to the interview appointment. All interviews were conducted after the completion of the posttest. Each course and section were represented by the interviewees. This was desirable since it provided data from across the spectrum of students and courses. Numerically, the interviewees included 3 students from Geography 1050a, 7 from Geography 1050b, 3 from Geography 1900a, 4 from Geography 1900b, 3 from Geography 1900c, 1 from Geography 1900d, and 3 from Geosciences 2900.

All interviewees were asked questions formulated around the atmosphere and weather objectives of the Michigan Curriculum Framework. The specific elementary (grades K-4) and middle school (grades 5-8) benchmarks are in Appendix B.

## Analysis of the Interviews

*Benchmark E.1.* The most basic of all the Michigan Curriculum Framework benchmarks is "Benchmark E.1: Describe weather conditions." The key concepts addressed by this benchmark include temperature (cold and warm), sky cover (clear, partly cloudy, cloudy, and foggy), precipitation (rain, snow, hail, and freezing rain), winds (breezy, windy, and calm), and severe weather (tornadoes, blizzards, thunderstorms, lightning, and high winds). Also included is the notion that the atmosphere is a blanket of air around the earth, and that air is a substance.

It was observed that the concepts addressed by this benchmark were addressed to a much greater depth through the remaining benchmarks. Therefore, the embedded content was applied within the interview questions for the remaining benchmarks and was readily identifiable. Students' knowledge about basic weather conditions were extracted from responses to interview questions about the following benchmarks.

*Benchmark E.2.* Students' knowledge, comprehension, and application skills with regard to "Benchmark E.2: Describe seasonal changes in Michigan's weather" was investigated by asking each interviewee to construct a drawing that explained why it is colder in Michigan during December and January than during June and July. In order to assure that the drawings were not simply mental copies or direct recall from the pretest/posttest, the researcher asked each interviewee to describe the components of his/her drawing and to explain how those components affect Michigan's seasonal weather changes.

All drawings constructed by the interviewees, as well as detailed descriptions of how the interviewees explained their drawings, are in the "Benchmark E.3" section of Appendix M.

Knowledge of the inclination of the earth was observed for the Geography 1050 sections and for the Geography 1900 and Geosciences 2900 inquiry-based sections. Knowledge about where the sun's direct rays shine on the Earth's surface at various times of the year was observed for the Geography 1050 sections and for the inquiry-based sections with the exception of Geosciences 2900. A lack of knowledge that the earth rotates on its axis and that its orbit around the sun is elliptical was observed for the two Geography 1050 sections and for the five inquiry-based sections.

Comprehension that the earth's inclination on its axis is the primary reason why it is colder in Michigan during December and January than it is in during June or July was observed for a majority of the interviewees in the Geography 1050 class sections but not for the majority of the interviewees in the inquiry-based sections. In comparing the

responses, interviewees in the Geography 1050 sections were generally unable to apply to other contexts their knowledge and comprehension regarding the tilt of the earth. They failed to recognize that the days in Michigan are longer during the summer and shorter during the winter. They could not explain how sunset times in Michigan are affected by the tilt of the earth. They were unable to explain when sun angles are the highest and lowest in Michigan. The interviewees in the inquiry-based Geosciences 2900 section were able to apply their knowledge that the earth is tilted to at least one context: they were able to explain when the sun angles are highest and lowest in Michigan.

These observations indicate that the most proficient examples of knowledge and comprehension with regard to "Benchmark E.2" were recorded for the Geography 1050 sections. Knowledge levels were observed among interviewees in the Geography 1900 and Geosciences 2900 inquiry-based sections, and application skills with regard to sun angles were applied in the Geosciences 2900 inquiry-based section. It is also noteworthy that interviewees in the Geosciences 2900 section expressed a lack of knowledge about where the sun's direct rays strike Earth at various times of the year. The earth-sun relationship model was not part of the formal curriculum for the Geosciences 2900 section. As a result, it appears that interviewees from Geosciences 2900 had not gained adequate knowledge about this aspect of the earth-sun relationship model to explain it effectively.

*Benchmark E.3.* In order to explore students' knowledge, comprehension, and application skills with regard to "Benchmark E.3: Explain appropriate safety precautions during severe weather," four major interview questions were asked.

First, interviewees were asked to differentiate between a severe weather "watch" and a severe weather "warning." Second, interviewees were asked to differentiate between a thunderstorm that is "severe" and one that is not. These questions explored students' understandings at the knowledge level. The content information needed to

answer these two questions is similar to the following information provided by the

National Weather Service (2006a):

[A severe thunderstorm watch] is issued by the National Weather Service when conditions are favorable for the development of severe thunderstorms in and close to the watch area. They are normally issued well in advance of the actual occurrence of severe weather. During the watch, people should review severe thunderstorm safety rules and be prepared to move a place of safety if threatening weather approaches.

[A severe thunderstorm warning] is issued when either a severe thunderstorm is...producing hail 3/4 inch or larger in diameter and/or winds equal or exceed 58 miles an hour; therefore, people in the affected area should seek safe shelter immediately... Lightning frequency is not a criterion for issuing a severe thunderstorm warning.

Third, interviewees were asked to describe what actions teachers and students

should take if they are inside a school when a tornado is approaching. This question explored students' proficiency at the application level. The content information needed to answer this question is similar to the following information provided by the National Weather Service (2006b):

Develop a severe weather action plan and conduct frequent drills. Children should kneel on the floor, putting their head on the ground and covering their neck with their hands. The neck and lower head are the most vulnerable parts of the body to flying debris. Schools without basements should use interior rooms and hallways on the lowest floor and away from windows. Large, high rooms are dangerous when a tornado is approaching. Gymnasiums, cafeterias, and auditoriums offer no protection in a tornado.

Fourth, students were asked whether or not it is appropriate to open the windows when a tornado is approaching. This question explored students' content proficiency at the comprehension level. An interviewee who possessed the content information necessary to answer this question would say that this is *not* an appropriate action because opening the windows would cause the force of the wind to enter the building. This potentially makes it easier for objects to be thrown around the room, and for the interior structure of the building to be weakened. It should be noted that some of the interviewees were not asked all of the questions. The flow of conversation sometimes resulted in one or two of the questions being emphasized to a greater depth, causing other questions to be passed over. This was the affect of time constraints for the interviews. Two Geography 1900a section interviewees were not asked the first question. Four Geography 1050a section interviewees and one Geography 1900c section interviewee were not asked the second question. Two Geography 1050a section interviewees were not asked the first question interviewees were not asked the first question interviewees were not asked the first question interviewees were not asked the first question.

The responses given by all interviewees about each of the four major interview questions are summarized in the "Benchmark E.3" section of Appendix M.

Knowledge with regard to the difference between a storm that is "severe" and one that is not was observed for the inquiry-based Geosciences 2900 class section. A preponderance of interviewees in the four inquiry-based Geography 1900 sections and in the two Geography 1050 sections were unable to recognize that a severe thunderstorm is characterized *only* by large hail and/or damaging wind.

Knowledge with regard to the difference between a severe weather "watch" and a severe weather "warning," and comprehension with regard to whether or not the windows should be opened when a tornado is approaching were observed for the Geography 1900c and Geography 1900d inquiry-based sections, and for the Geography 1050b section. A preponderance of interviewees in these sections was able to differentiate between a "watch" and a "warning," and was able to recognize that the windows should not be opened when a tornado is approaching.

Application skills with regard to actions that teachers and students should take if they are inside a school when a tornado is approaching were observed for a preponderance of interviewees in both the inquiry-based sections and in the Geography 1050 class sections. When asked what teachers and students should do when a tornado is approaching a school, interviewees in all class sections stated that it is important to get

away from the windows and move to the interior of the building or to a hallway, and expressed other life-saving strategies such as crouching down, covering the head with hands or a book, and staying inside.

Most of the concepts expressed in the interviews that were related to severe weather were not presented through the formal curricula of the inquiry-based sections. While knowledge, comprehension, and application skills were observed for the inquirybased sections, knowledge with regard to the difference between a "watch" and a "warning" and comprehension with regard to what actions to take when a tornado is approaching a school were not observed for all of the inquiry-based sections, and knowledge with regard to the criteria of a "severe" thunderstorm was observed only for the Geosciences 2900 section. This suggests that pre-service teachers who enrolled in the inquiry-based class sections did not gain the conceptual tools necessary to someday teach severe weather and severe weather safety precautions in ways that are consistent with the standards of the Michigan Curriculum Framework.

*Benchmark MS.1.* In order to explore students' knowledge, comprehension, and application skills with regard to "Benchmark MS.1: Explain patterns of changing weather and how they are measured," the researcher asked each interviewee to construct drawings that illustrated factors related to mid-latitude cyclones and anti-cyclones, and that consequently influence the weather in Michigan. An ideal application involved the construction of accurate drawings as well as the ability to describe and explain all of the components and to explain how the weather in Michigan is affected by each component.

All drawings constructed by the interviewees, as well as detailed descriptions of how the interviewees explained their drawings, are in the "Benchmark MS.1" section of Appendix M.

Knowledge with regard to several aspects of air masses and fronts was observed for the inquiry-based sections and for the Geography 1050 sections. This included interview responses that air masses are characterized by similar temperature and moisture

properties; that a front is the leading edge of an air mass; that specific names are given to air masses and fronts; and that warm fronts generally produce steady, light to moderate precipitation, while cold fronts generally produce strong-to-severe, but short duration, storms.

Students expressed knowledge about several aspects of wind patterns associated with mid-latitude pressure systems. This was observed for the inquiry-based sections and for the Geography 1050 sections. Examples were: Michigan is located within a prevailing westerly wind belt, that the winds in the Northern Hemisphere circulate clockwise around a high pressure and counter-clockwise around a low pressure, that air moves from high to low pressure, and that air rises at a low pressure and sinks at a high pressure. Knowledge about other aspects of wind patterns were observed for the inquiry-based class sections, including that jet streams exist and that the air deflects to the right as it comes out of a high pressure because of the coriolis effect (although interviewees could not explain that the coriolis effect was caused by the rotation of the earth).

Comprehension of how air masses form was not observed for a preponderance of interviewees in all class sections. Comprehension with regard to wind belts, jet streams, and the coriolis effect was observed for the Geography 1050b section. Interviewees in this section were able to explain how an air mass from the north or south could move into Michigan even though the prevailing wind is westerly.

Application skills with regard to air masses were observed for the inquiry-based Geosciences 2900 section and for the Geography 1050b section. Interviewees in these sections were able to identify the air mass over Michigan at the time of the interview.

Knowledge, comprehension, and application skills with regard to air masses were generally not observed for the inquiry-based Geography 1900 sections, but knowledge and application skills were observed for the Geosciences 2900 section. The topic of air masses was not part of the formal course curriculum for Geography 1900, but was part of the formal course curriculum for Geosciences 2900. The fact that knowledge and

application skills were applied in the Geosciences 2900 suggests that the inquiryapproach was effectively providing pre-service teachers with content necessary to teach according to the standards of the Michigan Curriculum Framework. However, the lack of comprehension with regard to how air masses form suggests that the depth of knowledge was inadequate.

An incorrect association of warm air with mid-latitude low pressure systems was observed for the inquiry-based sections, while an incorrect association of cold air with mid-latitude low pressure systems was observed for the Geography 1050 sections. Adequate descriptions of the precipitation patterns associated with mid-latitude high and low pressure systems were observed for the Geography 1050 sections but not for the inquiry-based sections. These findings indicate that knowledge, comprehension, and application skills with regard to weather patterns associated with mid-latitude pressure systems were not acquired through the inquiry-based sections, but were acquired through the Geography 1050 sections specifically about precipitation. This provides additional evidence that the effectiveness of the inquiry-based sections was inadequate.

*Benchmark MS.2.* In order to explore students' knowledge and comprehension skills with regard to "Benchmark MS.2: Describe the composition and characteristics of the atmosphere," the topic of "changes with altitude" was chosen from the "Key Concepts (vocabulary)/Tools" section of Benchmark MS.2 (Appendix B). Three questions were formulated related to how and why atmospheric pressure and air temperature change in the troposphere with respect to elevation or altitude. No application level questions were asked with regard to this benchmark.

First, each interviewee was asked a variant of the question, "What happens to your ears when you move from lower to higher elevations or altitudes in the troposphere?" Those who stated that the ears would pop were asked to explain *why* this would happen.

Second, interviewees were asked to explain how and why atmospheric pressure changes with an increase in elevation or altitude in the troposphere. Nine interviewees supplemented their responses to this question with a drawing, including two Geography 1050b interviewees, one Geography 1900a interviewees, one Geography 1900b interviewees, two Geography 1900c interviewees, the Geography 1900d interviewee, and two Geosciences 2900 interviewees.

Third, interviewees were asked to explain how and why air temperature changes with an increase in elevation or altitude in the troposphere.

The content information needed to answer the second and third questions is similar to the following information provided by *Ask a Scientist*, an online resource provided by the U. S. Department of Energy's Office of Science (United States Department of Energy, 2006):

Air pressure decreases with height because as you move up through the atmosphere, there is less and less air above you pushing down. Because pressure decreases with height, air expands as it rises. When the air expands, it uses up energy by pushing the surrounding air outward. The molecules in the air lose energy and slow down. So air cools as it rises and warms as it sinks. Rising air cools at a rate of 5.5 degrees F for every 1000 feet.

Not all of the interviewees were asked all of the questions. The flow of conversation sometimes resulted in one or two of the questions being emphasized to a greater depth, causing other questions to be passed over. This was the effect of limited time for the interviews. One Geography 1050a section interviewee was not asked the first question. One Geography 1050a section interviewee, one Geography 1050b section interviewee, all three Geography 1900a section interviewees, and one Geography 1900b section interviewee were not asked the third question.

The responses given by all interviewees for each of the three major interview questions are summarized in the "Benchmark MS.2" section of Appendix M. The
drawings created by the nine interviewees who constructed them are also in the "Benchmark MS.2" section of Appendix M.

Knowledge that the temperature decreases as one moves from lower to higher elevation or altitude, and that the ears "pop" or "get plugged," was observed for the inquiry-based sections and for the Geography 1050 sections. Knowledge that atmospheric pressure decreases with an increase in elevation or altitude was observed for the Geography 1050 sections and for the inquiry-based sections with the exception of Geosciences 2900.

Comprehension with regard to why the ears "pop" or "get plugged" was observed for the inquiry-based Geography 1900a and Geography 1900b sections. Interviewees in these sections were adequately able to explain that the pressure difference between the inside and the outside of the ears causes the ears to pop. Comprehension level responses were observed for two inquiry-based sections, suggesting that the inquiry-based sections had some success with regard to "Benchmark MS.2." Interviewees in these sections were able to explain beyond the simple assertion that it "has something" to do with pressure.

Comprehension about why atmospheric pressure decreases with an increase in elevation was generally not observed for the inquiry-based sections and for the Geography 1050b section, but was observed for the Geography 1050a section. Interviews in the four Geography 1900 sections were unable to discuss the relationship between pressure and elevation beyond a factual assertion. While pressure and elevation were addressed in the Geography 1050 class sections, there were no activities for Geography 1900 that specifically addressed the relationship between pressure and elevation. However, there was an activity for Geography 1900 that addressed the relationship between *temperature* and altitude. The relationship between pressure and elevation was included in an inquiry activity, but the reason for this relationship was never thoroughly explored through the activity. This lack of exploration may have prevented students from moving beyond a factual assertion of the relationship.

Interviewees in the Geosciences 2900 section incorrectly stated that atmospheric pressure *increases* with an increase in elevation. This is consistent with the findings of the "Item Analysis" of the pretest/posttest. Posttest responses for question 14 revealed that students in the Geosciences 2900 class section constructed a misconception that atmospheric pressure *increases* with an increase in elevation.

Comprehension with regard to why the air temperature decreases with elevation or altitude was not observed for the inquiry-based Geography 1900 and Geosciences 2900 sections or for the Geography 1050 sections. Interviewees in the inquiry-based sections were unable to explain the relationship between air temperature and elevation beyond a factual assertion. As mentioned above, there was an activity for Geography 1900 that addressed the relationship between temperature and altitude. This was a two page activity called "Lapse Rates" that required students to graph altitude data on the xaxis and temperature data on the y-axis. There was one question at the end of the activity that asked students to suggest reasons why air temperature decreases with height. Those responses were not explored through investigative activities. This lack of exploration may explain why students did not move beyond a mere factual assertion of the relationship between temperature and elevation.

*Benchmark MS.3.* In order to explore students' knowledge, comprehension, and application skills with regard to "Benchmark MS.3: Explain the behavior of water in the atmosphere," the topic of "aspects of the water cycle in weather" was chosen from the "Real-World Contexts" section of Benchmark MS.3 (Appendix B). This segment was always initiated with the interviewer asking the questions, "What is a cloud?" and "How does a cloud form?" All follow-up questions were based on how interviewees answered the initial questions, and so varied widely. The content information needed to answer this question is similar to the following information provided by *Ask a Scientist*, an online resource provided by the U. S. Department of Energy's Office of Science (United States Department of Energy, 2006):

Warm air can [contain] more water vapor (gas) than cold air. When warm moist air rises, it cools. Eventually it cools to the [dew] point where it is saturated with water vapor. At this point the water vapor begins to condense out as tiny droplets of liquid water...clouds form.

An interviewee who possessed the necessary content information would also state that the presence of particulate matter, or condensation nuclei, is necessary for condensation to occur.

The responses given by all interviewees are summarized in the "Benchmark MS.3" section of Appendix M.

Knowledge about certain aspects of cloud formation was observed for the Geography 1050 sections. Interviewees in these sections were able to articulate that warm air can contain more water vapor than cool air, and that air has to cool to the dew point for a cloud to form. However, a lack of knowledge about certain aspects of cloud formation was observed for the inquiry-based sections. Interviewees in these sections failed to recognize that warm air can contain more moisture than cool air. Interviewees in the Geography 1900 sections were unable to recognize that the air has to cool to the dew point for a cloud to form, although the majority of the interviewees in the Geosciences 2900 section were able to recognize this. Misconceptions were expressed that the temperature has to cool *below* the dew point in order to get a cloud, that a cloud exists in the form of water vapor or as water in a gaseous state or form, that a cloud is a form of precipitation, and that the dew point is a percentage. Some interviewees recognize the importance of condensation nuclei, but the majority did not.

Comprehension and application skills with regard to the processes involved in cloud formation were not observed for a preponderance of interviewees in the Geography 1050 sections. Interviewees in these sections provided very little explanation for how a cloud forms. In addition, they could not explain the role of particulate matter in cloud formation, and they were unable to state that a cloud exists in the form of a liquid. On the other hand, comprehension with regard to the processes involved in cloud formation

(the evaporation of surface water, the role of the sun as the ultimate source of energy, atmospheric convection, the cooling of rising air, the amount of moisture in the air, etc.) was observed for the inquiry-based class sections.

The fact that the interviewees in the inquiry-based sections demonstrated comprehension of processes involved in the formation of a cloud provides evidence that Geography 1900 and Geosciences 2900 are developing problem solving skills as intended in their inquiry instructional designs. It seems surprising, however, that interviewees in the Geography 1900 sections failed to recognize that the air has to cool to the dew point, given that there was a Geography 1900 activity for which the goal was to find the dew point. Students placed ice in a small tin can containing water, and a thermometer was placed in the water to measure the decrease in temperature as more and more ice was added to the tin can. The temperature of the water at the moment water droplets appeared on the side of the tin can was the dew point. However, a significant problem occurred when students tried to conduct this activity during the late autumn of 2004 and late winter of 2005. The dew point during both of these periods was below freezing. However, by mixing ice with water, students were only able to lower the water temperature to or just slightly above the freezing point. Students were unable to observe the dew point. This may have hindered their ability to apply the principle that the air has to cool to the dew point in order for condensation to take place, and thus for a cloud to form.

*Benchmark MS.4.* In order to explore students' knowledge, comprehension, and application skills with regard to "Benchmark MS.4: Describe health effects of polluted air," the topic of "ozone warnings" was chosen from the "Real-World Contexts" section of Benchmark MS.4 (Appendix B). Interviewees were asked to define an "ozone action day" and explain why such days are declared. The content information needed to answer this question is similar to the following information provided by the Environmental Protection Agency (2006):

Ground-level ozone, the main ingredient in smog that can cause damage to your lungs, is a significant health problem in many Midwest cities during the summer months. Several cities have organized Ozone Action Day programs in which citizens, businesses, local, State and Federal governments, and health and environmental organizations are asked to take voluntary actions to help reduce ozone forming emissions on Ozone Action Days. An Ozone Action Day will be called when weather forecasters have predicted that conditions will be conducive to the formation of ozone. Ozone is sometimes chemically abbreviated as O<sub>3</sub>.

The ozone layer, miles above the surface of the earth, protects us from cancer causing solar ultraviolet radiation. But ground level ozone damages our lung tissue. This harmful ozone is formed through a complex chemical reaction involving hydrocarbons, nitrogen oxides and sunlight on calm summer days.

Ozone causes shortness of breath, coughing, wheezing, and eye and nose irritation. It is especially dangerous to older adults, children, asthmatics and persons with other chronic respiratory ailments. While most people think of industry as the main source for air pollution, the fact is that approximately HALF of the hydrocarbons emitted come from actions of ordinary citizens as we drive our cars, maintain our homes and use a variety of volatile chemicals.

Ozone Action Days will be announced during weather forecasts on radio and television. An Ozone Action Day will be called when State weather forecasters predict that weather conditions will be conducive for the formation of ozone. Newspapers may also have announcements in their weather sections.

The responses given by all interviewees are summarized in the "Benchmark

MS.4" section of Appendix M.

A lack of knowledge, comprehension, and application skills with regard to the purpose of an "ozone action day" and about ground level ozone and its related health concerns was observed for all class sections. None of the interviewees were able to define an "ozone action day." There were even interviewees in both the Geography 1050 class sections and the inquiry-based class sections who directly stated that they had never heard of an "ozone action day" before taking the pretest/posttest, or that they had heard of it but did not know the meaning. Many incorrectly stated that an "ozone action day" is issued for the purpose of protecting the ozone layer above the earth, or to prevent the

"hole" in the ozone layer from becoming bigger. One Geography 1900b section interviewee even thought that an "ozone action day" is issued in order to *reduce* the amount of ozone that is going into the ozone layer that surrounds the earth. The topic of "ozone action days" was not addressed through the formal curriculum of any of the class sections.

## Interviewee S-9

One of the Geography 1900a interviewees (S-9) was interviewed a second time after completing the meteorology unit in Geosciences 2900. This was done in order to identify areas of for which there was growth in knowledge, comprehension, and application skills from one course to the other. S-9 was the only student who was interviewed twice. This interviewee was asked the same questions during both interview sessions.

For both interview sessions, the drawings constructed by S-9 to model the earthsun relationship demonstrated knowledge that the earth is inclined on its axis. However, it was only during the Geosciences 2900 interview session that S-9 verbally explained that the inclination of the earth is the primary reason for why it is colder in Michigan during December and January than it is during June and July. S-9 expressed several concepts about the earth-sun relationship model during the Geosciences 2900 interview session that were not expressed during the Geography 1900a interview session, including making statements that the sun's rays in Michigan are never as high as 90° above the horizon and the sun's direct rays can shine at the equator but not at the North Pole.

S-9 was able to identify the criteria for a severe thunderstorm even though no such knowledge was expressed during the Geography 1900a interview session. The general area of severe weather was not addressed through the formal course curriculum of Geosciences 2900. However, severe thunderstorms were briefly addressed during a Geosciences 2900 activity related to mid-latitude cyclones. One of the many purposes of

this activity was to help students understand that light to moderate precipitation is typically found along warm fronts, while brief but strong-to-severe thunderstorms are typically found along cold fronts.

S-9 expressed several concepts about weather that were not expressed during the Geography 1900a interview session, including knowledge that an air mass is characterized by similar or uniform temperature and humidity, comprehension about how air masses form, knowledge of specific names given to air masses that influence the weather in Michigan, knowledge that "cold" and "warm" are two types of fronts that move through Michigan, knowledge that air moves from high to low pressure, knowledge that winds rotate counter-clockwise around a low pressure and clockwise around a high pressure in the Northern Hemisphere, and comprehension that there is not necessarily a direct relationship between surface air temperature and pressure systems. S-9 was able to apply this knowledge and comprehension by explaining the types of weather that Michigan experiences with high and low pressure systems. No knowledge, comprehension, or application with regard to any of these areas were expressed by S-9 during the Geography 1900a interview session.

S-9 expressed a similar level of understanding about the water cycle during the Geosciences 2900 interview session to what was expressed during the Geography 1900a interview session. However, there was one area for which growth was observed. S-9 stated that in order to get a cloud, the air has to cool to the dew point. No such knowledge was expressed during the Geography 1900a interview session.

It is noteworthy that S-9 demonstrated growth during the Geosciences 2900 interview session. The fact that S-9 had acquired additional knowledge, comprehension and application skills with regard to several benchmarks demonstrated the success that was anticipated for the inquiry course design. However, this single example may represent an anomaly and the observations justify further research.

# CHAPTER V

## CONCLUSIONS

The results of this study contribute significant information about the effect of the inquiry approach to pre-service teacher education at Western Michigan University. The object of the research was to discover whether or not the inquiry-based courses designed and supervised by the Mallinson Institute for Science Education are more effective than traditional science courses in enabling pre-service teachers to be more proficient with the science content standards in the Michigan Curriculum Framework. Though this study focuses exclusively on atmospheric science content, it is the first in-depth study completed that addresses this question.

A statistically significant pre- to posttest improvement for the overall student performance in a test to measure knowledge, comprehension, and application skills was not observed for the inquiry-based Geography 1900 class sections or for the inquirybased Geosciences 2900 class section. Student improvement on tests was observed only for two traditional lecture/laboratory-based Geography 1050 class sections. This provides evidence that neither Geography 1900 nor Geosciences 2900 adequately prepared pre-service teachers to teach consistently with the atmospheric science standards of the Michigan Curriculum Framework, while the Geography 1050 course did provide pre-service teachers information which they were able to reproduce on the test instrument.

Analysis of the pretest/posttest items revealed evidence that students in the inquiry-based class sections accomplished some improvements in knowledge, comprehension and application skills. Those improvements did not result in statistically

significant improvements on the overall posttest scores. The lack of improvement that was observed for the application questions suggests that the inquiry-based courses were not effective at enabling pre-service teachers to apply the processes of sciences on pen and paper tests for the content areas outlined within the science standards of the Michigan Curriculum Framework.

Analysis of the pretest/posttest improvement revealed evidence that students in the Geography 1050 course accomplished improvements in knowledge and comprehension that resulted in statistically significant improvements on the overall preto posttest difference scores. It appears that Geography 1050 better prepared pre-service teachers to teach content according to the Michigan Curriculum Framework. Further evidence that the Geography 1050 course better prepared pre-service teachers was observed in the analysis of the classroom observations. There were two Geography 1050 lecture sessions for which *Flexible Teaching Modules for Physical Geography* ("Blown Away" and "Campus Thermal") were used. These sessions were observed to be highly consistent with inquiry-based national and state standards.

The interpretation of the classroom observations and the interview sessions revealed at least three explanations for the failure of the inquiry-based courses to bring about significant pre- to posttest improvements.

First, the inquiry-based courses were not fully consistent with the inquiry-based national and state standards even though both Geography 1900 and Geosciences 2900 were more consistent with the inquiry-based national and state standards than were the Geography 1050 lecture and laboratory sessions. For the Geography 1900 course, mean ratings in the middle of the 7-point coding scale were observed for all "overall" ratings and for the majority of the questions. This indicates that the Geography 1900 course was only partially consistent with the inquiry-based state and national standards. For the Geosciences 2900 course, mean ratings on or near the high end of the scale were observed for one "overall" rating and for 8 individual questions. However, the majority

of the "overall" ratings and individual questions for the Geosciences 2900 course received mean ratings in the middle of the 7-point coding scale. This indicates that, similar to the Geography 1900 course, the Geosciences 2900 course was not fully consistent with the inquiry-based state and national standards as was intended by the course design.

Second, the inquiry-based class courses were observed to include laboratory activities that did not adequately use investigative procedures. That may have hindered the growth of students' knowledge, comprehension, and application performance on the research instrument. For example, an activity on lapse rates required students to graph altitude data on the x-axis and temperature data on the y-axis. This activity also required students to suggest reasons why the air temperature decreased with height, but these reasons were not explored through investigations. This may provide the explanation for why interviewees were generally unable to explain the relationship between temperature and elevation beyond the mere assertion that a relationship exists. It was also observed that some activities were ineffective. For example, students mixed ice into a tin can containing water while a thermometer was used to measure the change in temperature of the water. When students first observed droplets forming on the side of the tin can, the temperature of the water at that moment was the dew point. However, this activity did not function well during the colder times of the year (late fall and later winter) when the dew points were below the freezing point. This may explain why interviewees generally were not able to apply the principle that the air has to cool to the dew point in order for condensation to occur and for clouds to form.

Third, the inquiry-based courses lacked several major content areas outlined by the Michigan Curriculum Framework on which the research instrument was based. There were at least five important areas that were not addressed through the classroom activities of at least one of the inquiry-based courses:

- 1. Seasonal changes in Michigan's weather were not directly addressed through the formal course curriculum for Geosciences 2900, but were addressed for Geography 1900.
- 2. The general topics of severe weather and severe weather safety precautions were not addressed by Geography 1900 or Geosciences 2900, although the topic of "severe" thunderstorms was briefly addressed in a Geosciences 2900 laboratory activity related to mid-latitude cyclones.
- 3. Activities related to air masses were part of the formal course curriculum for Geosciences 2900, but not for Geography 1900.
- 4. The relationship between atmospheric pressure and elevation or altitude in the troposphere was addressed through the formal course curriculum for Geography 1900, but not for Geosciences 2900.
- 5. Atmospheric environmental issues of local importance, such as ground level ozone and its impacts on human health, were not addressed through the classroom activities for either Geography 1900 or Geosciences 2900.

Evidence from the interview sessions and the pretest/posttests suggests that not including

these content areas has resulted in a significant lack of factual, comprehension, and

application understanding ands skills among students that are clearly identified as

expectations in the Michigan Curriculum Framework:

- 1. Interviewees in the Geosciences 2900 course generated significant misconceptions related to the earth-sun relationship model, while interviewees in the Geography 1900 course generated no such misconceptions.
- 2. Interview sessions and pretest/posttest responses for question 7 ("What are the *minimum* criteria that will cause the National Weather Service to issue a severe thunderstorm "warning" for your county?") revealed that interviewees in the inquiry courses demonstrated a general lack of factual knowledge about how a severe weather "watch" differs from a severe weather "warning" and about whether or not the windows should be opened when a tornado is approaching a school.
- 3. Interviewees in the Geography 1900 course did not express any factual knowledge about specific names given to air masses that influence the weather in Michigan, although such factual knowledge was expressed by Geosciences 2900 and Geography 1050 interviewees.
- 4. Interview sessions and pretest/posttest responses for question 14 ("What happens to the air temperature and atmospheric pressure as elevation increases?") revealed that students in the Geosciences 2900 course generated a misconception that atmospheric pressure increases with an increase in elevation. On the other hand, students in the Geography 1900 course generally had knowledge that atmospheric pressure decreases with elevation

5. Interviewees in the inquiry-based courses were unable to define what an "ozone action day" is. They were also unable to express knowledge, comprehension, or application levels of understanding about ground level ozone. Many interviewees incorrectly associated "ozone action days" with a "hole" in the ozone layer that surrounds the earth.

These conclusions from the research highlight the importance of stressing *all* of the Michigan Curriculum Framework benchmarks in the inquiry-based courses. Failure to do so appears to have resulted in students gaining little or no understanding about important topics (as was observed among interviewees for ground level ozone and "ozone action days"), and in students generating significant misconceptions about other important topics (as was observed among interviewees for the earth-sun relationship model). Part of the problem may result from the division of the meteorology unit into two components in two courses. The first half of the meteorology unit was presented in Geography 1900, while the second half of the meteorology unit was presented in Geosciences 2900. Students, however, were allowed to enroll in Geosciences 2900 even though they had not completed Geography 1900, and students who completed Geography 1900 were not required to enroll in Geosciences 2900. This may have resulted in many students gaining only a partial understanding of the meteorology unit. While the research data suggest that the inquiry-based courses were not fully accomplishing the intended objectives, they did assist students to learn important knowledge, comprehension, and application principles of meteorology. For example, during the interview sessions, students were able to explain the processes related to cloud formation and why the ears "pop" as elevation increases, and they were able to identify the air mass over Michigan at the time of their interview sessions.

Overall, the inquiry courses that were examined for this study did not fully prepared pre-service teachers. If these courses are to be beneficial for pre-service teachers, the Mallinson Institute for Science Education may need to redesign the content

and instructional approaches of the meteorology unit. The findings of this study suggest that this could be accomplished in at least four ways:

First, the two parts of the inquiry-based meteorology unit could be combined. Dividing the meteorology content between the Geography 1900 and Geosciences 2900 courses may have disconnected important atmospheric science topics from one another. Students who encountered just one of the inquiry-based courses were not presented important aspects of atmospheric science that were components of the other course. The researcher recommends that the entire meteorology unit be presented in one course. Interestingly, this change has been implemented since the time that the data for this study were collected. Beginning with the Fall 2005 semester, all of the atmospheric content from the Geosciences 2900 course was moved to the Geography 1900 course, and all of the geology and hydrology content from the Geography 1900 course was moved to the Geosciences 2900 course. Geography 1900 is now a course that is fully devoted to the teaching of atmospheric science content. The data from this study support that this was an appropriate decision.

Second, new activities could be implemented into the inquiry-based meteorology unit in order to address topics within the Michigan Curriculum Framework that are not currently being addressed. There were at least two benchmark areas for which little or no content was presented in the inquiry-based meteorology unit: severe weather safety precautions and the health effects of polluted air. The analysis of the pretest/posttest and of the interview sessions revealed misconceptions about severe weather among students. The analysis of the interview sessions revealed that students in the inquiry-based courses had developed inadequate knowledge, comprehension, and application skills with regard to ground level ozone and its related health effects. These observations would not likely have been serious if there had been activities to address these benchmarks within the inquiry-based courses. Content validity is the issue relative to the research instrument, but the goal of the research was to ascertain content proficiency among students in

inquiry and traditional courses. Activities that are added to the inquiry-based course curricula should be aligned with the state of Michigan Curriculum Framework. In addition, when investigative procedures form the basis of the activities, there needs to be increased attention to factors that influence the environment and climate of Michigan.

Third, *Flexible Teaching Modules for Physical Geography* could be implemented into the courses. There is potential for the courses to become more inquiry-based if these modules are implemented, or if laboratory activities are designed to make use of the approaches employed by the modules. Since the time that the data for this study were collected, additional Flexible Teaching Modules for Physical Geography have been added to the Geography 1050 course, including one related to global pressure and another called "Warren Dunes" that makes use of a mosaic image of a sand dune from Warren Dunes State located along the eastern shore of Lake Michigan. As more of these inquirybased modules are created, some of them could focus on science content emphasized by the Michigan Curriculum Framework in order to benefit pre-services teachers. These modules could be used in either the Geography 1050 course or the inquiry-based courses. It would not be reasonable to expect that all of the modules focus on such content, given that students from many different university programs enroll in Geography 1050. However, given that the background analysis revealed that 31% of the Geography 1050 students were pre-service teachers, and given that these modules could be implemented into the inquiry-based courses, it seems reasonable to suggest that some of the course content be designed for pre-service teachers.

Fourth, the SAMPI Lesson Observation System ratings could be used as a guide for analyses and repurposing those aspects of inquiry based instruction that need improvement. The interpretation of the classroom observations revealed components of the inquiry-based courses that need to be made more consistent with the inquiry-based state and national content standards. Full details of the strengths and weaknesses of these class sections are provided within the "Interpretation of the Ratings" part of this

dissertation. The ratings assigned for each component and for each of the component questions could therefore be used by course designers to focus on those areas which are not functioning at the expected inquiry level. One area is connection to other subjects. Low mean ratings were observed for this component question for all inquiry classes. This indicates that designers need to integrate "the key ideas and processes of the current lesson and previous or future science units/topics" (Science and Mathematics Program Improvement; 2003a, p. 7). One way that this could be accomplished is through the addition of "Discussion" items to the course pack activities. Those "Discussion" items could involve instructors asking questions about "how the core ideas of the current lesson relate to previous or future science unit/topics" (Science and Mathematics Program Improvement; 2003a, p. 7), or they could require students to use class time to "identify and/or discuss connections" (Science and Mathematics Program Improvement; 2003a, p. 7).

# Limitations

While the design of this research project included most of the characteristics of a *quasi-experimental control group* design (Campbell & Stanley, 1963), the selection of the subjects was neither random nor under the control of the researcher. This should be seen as a limitation to this study. Students were asked to participate on the sole basis that they had chosen to enroll in one of the class sections that were available for inclusion in this study. This type of selection process is referred to as a *sample of convenience*. The object of such a selection process is described as follows (Ferber, 1977; p. 57):

The object...[of a convenience sample is] to make it as simple and economical as possible for the researcher to get a set of data. For this reason, it is not surprising that a convenience sample for a commercial researcher may be picked up on the street or in a shopping center, while for an academic researcher a convenience sample is usually whatever classes that individual happens to be teaching at the time. There were other factors that were viewed as potential limitations to this study. The fact that participation was voluntary was one such example. Due to the requirements imposed by the Human Subjects Institutional Review Board (HSIRB) of Western Michigan University, the researcher could not require that students participate in this study. Students therefore had the option to refuse any and all involvement. If a significant number of students from a particular class section had elected not to partake, then the findings for that class section would not have been generalizable to the entire population of students enrolled in that class section. However, there were very few instances of this actually happening. Nearly all students who were enrolled in the class sections that were available on the data collection dates elected to participate.

There was also a concern that some students would elect to withdraw from the study after completing the pretest. This is known as "experimental mortality" (Babbie, 2001; p. 227) and was likely to occur to some extent even though the pretest/posttest was completed during classroom or laboratory time. This could have distorted the results of the study. This concern, however, also proved to be unwarranted. Only three Geography 1050 students and four Geography 1900 students who completed the pretest did not complete the posttest. All Geosciences 2900 students who completed the pretest also completed the pretest. Student data were included in the study only if the student completed both the pretest and posttest.

Another potential limitation to this study related to how the Geography 1900 and Geosciences 2900 courses were designed. These courses were revised from the original prototype with the standards of the Michigan Curriculum Framework as the standard of reference for content. Geography 1050 was not. It therefore seemed likely that the students enrolled in the Geography 1900 and Geosciences 2900 class sections would become more proficient with earth science concepts emphasized by the Michigan Curriculum Framework by virtue of the fact that the courses were aligned with the framework. This made it difficult to determine whether any growth in understanding was

actually due to the emphasis that was placed on inquiry as a teaching strategy. This concern was addressed in part through the coding of the hand-written classroom observations. The SAMPI Lesson Observation System made it possible to make a determination regarding the "traditional" or "inquiry-based" nature of the various class sections incorporated in the research. Appendix A

An Example Benchmark and Clarification

More Benchmarks details can be found at the following web sites:

Elementary Earth science benchmarks: http://www.orbro.com/miclimb/DocPieces/st5el\_frame.html

Middle school Earth science benchmarks: http://www.orbro.com/miclimb/DocPieces/st5ms\_frame.html

# Here are details from these web sites for a sample benchmark:

## Benchmark

Describe major features of the Earth's surface (SCI.V.1.E.1).

## **Benchmark Clarification**

The Earth's surface has many different kinds of physical features.

Students will:

- Describe the Earth's surface in different locations
- Distinguish between features such as mountains/hills, mountains/plains, mountains/valleys, grasslands/desserts, oceans/lakes, rivers/waterfalls, and lakes/streams.

#### Key Concepts (voc.)/Tools

Types of landforms:

- mountains
- plains
- valleys
- desserts

See SCI.V.2.E.2.

Bodies of water:

- rivers
- oceans
- lakes

## **Real-World Context**

Examples of Michigan features:

- hills
- valleys
- rivers
- waterfalls
- Great Lakes
- pictures of Global land features
  - mountains
  - desserts

- valleys
- plains

#### Instructional Example SCI.IV.1.E.1

**Benchmark Question:** What is the Earth's surface like?

Focus Question: How could you describe the major features of the Earth's surface?

The teacher will pose the focus question. The students will look for pictures in old magazines or online that reflect all oft he key concepts. Upon completion of their research, students will classify their pictures based on physical features. During the classification process, students will come to a consensus on how to describe the features. The student will present their pictures and explain the reasoning fort heir classifications orally. The teacher should monitor students for misconceptions. What might be some misconceptions that students would have?

Constructing: SCI.I.1.E.1), SCI.I.1.E.5)

**Reflecting:** SCI.II.1.E.1

Resources/References: Webliography. http://mtn.merit.edu/mcf/SCI.V.1.E.1.html

Earth from Above: uses the Flash format to feature the amazing photos of Yann Arthus-Bertrand. Images exist for all sorts of physical and cultural phenomena, especially agriculture. Choose images by geographic locale or from an index. Animated clips and screensavers are also available. http://home.fujifilm.com/efa/

Color Landform Atlas of the U.S. offers shaded relief maps (larger file size), county maps, black and white maps, satellite images, 1895 maps (Big: 1.92 Mb), and postscript file maps for printing of all 50 states. http://fermi.jhuapl.edu/states/states.html

Geomorphology from Space: "237 plates, each treating a geographic region where a particular landform theme is exemplified. Commentary, photographs, location maps, and sometimes a geologic map accompany each plate."

 $http://daac.gsfc.nasa.gov/DAAC\_DOCS/geomorphology/GEO\_HOME\_PAGE.html$ 

Cole, Joanna. The Magic School Bus: Inside the Earth. Scholastic, 1989.

Earth's features. http://encarta.msn.com

Physical features. http://walrus.wr.usgs.gov/docs/ask-a-ge.html

Stille, Darlene. Desserts. TRUE BOOKS ECOSYSTEMS SERIES. Children's Press, 1999.

#### Classroom Assessment Example SCI.V.3.HS.4

Students will illustrate and write descriptions of six or more major features of the Earth's surface.

(Give students rubric before activity.)

Scoring of	Classroom	Assessment	Example	SCLV1F1
Scoring of	Classicolli	Assessment	Example	SCI. V.I.L.I

Scoring of Classroom Assessment Example SCI.V.1.E.1				
Criteria	Apprentice	Basic	Meets	Exceeds
Number of	Illustrates four or	Illustrates five	Illustrates six	Illustrates more
Illustrations	fewer major	different major	different features	than six different
	features of the	features of the	of the Earth's	features of the
	Earth's surface.	Earth's surface.	surface.	Earth's surface.
Completeness of	Writes four or	Writes five	Writes six	Writes more than
descriptions	fewer descriptions	descriptions of	descriptions of	six descriptions of
	of major features	major features of	major features of	major features of
	of the Earth's	the Earth's surface.	the Earth's surface.	the Earth's surface.
	surface.			

Appendix B

Atmosphere and Weather Objectives for Elementary and Middle School Levels (Michigan State Board of Education)

# Strand V: Using Scientific Knowledge from the Earth and Space Sciences in Real-World Contexts

Content Standard 3: All students will investigate and describe what makes up weather and how it changes from day to day, from season to season, and over long periods of time; explain what causes different kinds of weather; and analyze the relationships between human activities and the atmosphere.

## Benchmarks

Atmosphere and Weather	Elementary	Middle School
What makes up weather and how	1) Describe weather conditions.	4) Explain patterns of changing
does it change from day to day,		weather and how they are
from season to season, and over	2) Describe seasonal changes in	measured.
long periods of time?	Michigan's weather.	
		5) Describe the composition and
		characteristics of the atmosphere.
What causes different kinds of	This question addressed by	6) Explain the behavior of water
weather?	objectives at another level.	in the atmosphere
What are the relationships	3) Explain appropriate safety	7) Describe health effects of
between human activities and the	precautions during severe	polluted air.
atmosphere?	weather.	

Benchmarks and Clarifications	Key Concepts (voc.)/Tools	Real-world contexts
for Elementary School		
1. Describe weather conditions.	Atmosphere is a blanket of air	Daily changes in weather
<u>(SCI.V.3.E.1).</u>	around the Earth; air is a	
At any given time, various weather	substance	Examples of severe weather
conditions occur on the Earth.		
These conditions change in a	Attributes of substances	
predictable pattern. Daily changes		
and severe weather can be	See Atmosphere (SCI.IV.I.E.I).	
observed. Students will: observe		
weather conditions (temperature,	The temperature of air is: <i>cold, hot,</i>	
cloud cover, precipitation, wind),	warm, cool	
distinguish among different types		
of severe weather (tornadoes,	Cloud cover: <i>clear</i> , <i>cloudy</i> , <i>partly</i>	
blizzards, thunderstorms,	cloudy, foggy	
hurricanes, lightning, high winds,		
droughtsstudents are more likely	Precipitation: rain, snow, hail,	
to experience this than tornadoes).	freezing rain	
	Wind: breezy, windy, calm	
	Severe weather: tornadoes,	
	blizzards, thunderstorms,	
	lightning, high winds (of greatest	
	importance to students would be	
	the dangerous impact of cold	
	temperatures and wind chill. Wind	
	chill and its effects should be	
	included in the discussion of high	
	winds.)	
	Tools: thermometer, wind sock,	
	rain gauge	
2. Describe seasonal changes in	Seasons and types of weather: <i>fall</i>	Examples of visible seasonal
Michigan's weather. (SCI.V.3.E.2).	(cool nights and warm days, day	changes in nature.
Michigan's weather changes with	length getting shorter), winter	C
the seasons. Changes in weather	(snowy and cold, getting dark early	
will include: temperature,	in the evenings), spring (warmer	
precipitation (rain, snow), number	days, often rainy with	
of hours of sunlight. Students will:	thunderstorms, days length getting	
compare and contrast seasonal	longer), summer (warm or hot days	
changes in weather (e.g., fall,	and warm nights, daylight lasting	
winter, spring, summer), describe	until late in the evenings)	
the effects of seasonal changes		
on: vegetation, human activities.		

Knowledge, Activity, and Content Dimensions (Elementary School)

Benchmarks and Clarifications	Key Concepts (voc.)/Tools	Real-world contexts
for Elementary School		
3. Explain appropriate safety	Safety precautions: safe locations,	Examples of local severe weather
precautions during severe weather.	sirens, radio broadcasts, severe	that changes with the seasons:
(SCI.V.3.E.3).	weather watch and warning.	thunderstorms, tornadoes,
Appropriate safety precautions	Students need to know the	blizzards, wind chill, heat index
need to be taken during severe	difference between a watch	
weather. Safety precautions	(conditions favorable) and a	Examples of local community
include moving to safe locations,	warning (tornado has actually been	safety precautions: weather
listening for sirens, and monitoring	sited on the ground).	bulletins, tornado sirens
radio broadcasts for severe weather		
watches and warnings. Students	See Atmosphere (SCI.IV.1.E.1).	
will: explain safety precautions		
during severe weather such as high		
wind chill events, high heat index,		
ozone alert, thunderstorms,		
tornadoes, and blizzards;		
demonstrate safety precautions		
they should take during a high wind		
chill events, high heat index, ozone		
alert, thunderstorms, tornado, and		
blizzard.		
While tornadoes, thunderstorms,		
and blizzards are significant events		
and students need to know how to		
properly respond to these events,		
the frequency of these events is		
less than days when the wind chill		
and heat index is high. Students		
need to know what type of		
precautions to take for these two		
events as well.		

Benchmarks and Clarifications	Key Concepts (voc.)/Tools	Real-world contexts
for Middle School		
4. Explain patterns of changing	Weather patterns: <i>cold front</i> ,	Sudden temperature, pressure,
weather and how they are	warm front, stationary front, air	and cloud formation changes
measured. (SCI.V.3.MS.1).	mass, humidity	
Weather scientists/meteorologists		Records, charts, and graphs of
try to predict the weather. They	Tools: thermometer, rain gauge,	weather changes over periods of
use a variety of instruments to	wind direction indicator,	days
measure weather in order to	anemometer, weather maps,	
develop patterns. They base their	satellite weather images, cloud	Lake effect snow
predictions on these	charts, barometer	
measurements and patterns.		
Students will: use weather maps		
and satellite images to detect		
weather patterns; use weather		
maps and satellite image		
information to write weather		
predictions; manipulate a variety of		
weather measuring instruments to		
measure temperature, wind speed.		
and direction, cloud cover,		
humidity, dew point, amount of		
rainfall, and other weather		
phenomena.		
<u> </u>		
5. Describe the composition and	Composition: <i>air</i> , <i>molecules</i> , <i>gas</i> ,	Examples of characteristics of the
characteristics of the atmosphere.	water vapor, dust particles	atmosphere: <i>water boils at</i>
(SCLV.3.MS.2).	1 1 1	different temperatures at different
Human and natural activities affect	Characteristics: <i>air pressure</i>	elevations, pressurized cabins in
the atmosphere. Scientists have	changes with altitude, temperature	airplanes, demonstration of air
collected data about the	changes with altitude, humidity	pressure
atmosphere from weather balloons		p i cootti c
weather airplanes satellites and		Examples of air-borne particles:
computer modeling Students will:		smoke dust pollen bacteria
evolution the chamical composition		smoke, dusi, polien, bucienti
of the atmosphere using molecular		Effects of humidity: condensation
components like nitrogen orveen		daw on surfaces comfort lavel
water vapor and other pases:		of humans
describe the atmosphere using		oj numuns
characteristics such as air		
characteristics such as air		
pressure, temperature changes,		
ana numialiy.		

# Knowledge, Activity, and Content Dimensions (Middle School)

Benchmarks and Clarifications	Key Concepts (voc.)/Tools	Real-world contexts
for Middle School		
6. Explain the behavior of water in	Water cycle: evaporation,	Aspects of the water cycle in
the atmosphere. (SCI.V.3.MS.3).	water vapor, warm air rises,	weather: clouds, precipitation,
Water moves through the	cooling, condensation, clouds	evaporating puddles
atmosphere in a pattern called the	-	
water cycle. As it moves through	See Changes of State	
the atmosphere, water changes	(SCI.IV.2.MS.1).	
states from a solid to a liquid, from		
a liquid to a gas, and from a liquid	See Water of the Earth's Surface	
to a solid. Students will:	(SCI.V.2.MS.2).	
investigate various forms of water		
in the atmosphere; explain how	Precipitation: rain, snow, hail,	
water changes states as it moves	sleet, freezing rain	
through the water cycle by using		
the terms evaporation,		
condensation, and precipitation.		
7. Describe health effects of	Effects: breathing difficulties,	Locations and times where air
polluted air. (SCI.V.3.MS.4).	irritated eyes	quality is poor
Polluted air affects people's health		
in many ways. Pollution can be	Sources (man-made): car exhaust,	Local sources of potential air
man-made or naturally occurring.	industrial emissions, acid rain	pollution
Students will: research causes of		
natural pollution (pollen, carbon		Ozone warnings
dioxide, ozone, sulfur dioxide,		
etc.) and the effects these		
pollutants have on human health;		
research man-made pollution (car		
exhaust, power plant emissions,		
industrial emissions, etc.) and the		
effects these pollutants have on		
human health; recommend		
solutions that will minimize the		
harmful effects of air pollutants on		
humans.		
<b>Note:</b> Indoor pollution needs to		
be considered, given the fact that		
we spend 90% of our time indoors		
and that many of the pollutants		
that we fear are higher inside the		
house than outside. See web link		
listed in resources.		

Appendix C

Study Introduction

## Dear students:

My name is Robert Ruhf. I am a doctoral student with the Mallinson Institute for Science Education at Western Michigan University, and I am conducting a study on the learning of Earth science among pre-service teacher education students. You do not have to be an education student to participate. The findings of this research will provide the faculty of three departments with much needed insights related to the effectiveness of various courses. Your class has been selected to take part in this research, although your individual participation is entirely voluntary. If you choose to participate, you will be one of among approximately 200 total participants from several classes.

You will be asked to complete two tests. The first test will be given at the beginning of this semester. It should take approximately thirty (30) minutes to complete. You will be asked several questions related to key concepts in a particular area of Earth science, as well as real world applications of these concepts. You will be asked to answer all questions as best you can. This test will contain a background question page on which you will be asked to provide your name and to answer several questions about your personal background. You must include your name on the cover page, but *you may choose to not answer any or all of the background questions.* You will be used to evaluate the growth in your level of understanding as a result of taking this course.

Approximately 10% of you will be randomly selected to participate in two interview sessions, the first of which will be conducted during the early part of this semester, and the second of which will be conducted at the start of the next semester. These sessions will not exceed 20 minutes each. All question asked during the interview sessions will relate to your understanding of Earth science. *You may choose to not participate in the interview sessions even if you complete the tests.* 

All of the information collected from you is confidential. That means that your name will not appear on any papers on which this information is recorded. The forms will all be coded, and I will keep a separate master list with the names of participants and the corresponding code numbers. Once the data are collected and analyzed, the master list will be destroyed. All other forms will be retained for at least three years in a locked file in Dr. Joseph Stoltman's office.

You may refuse to participate in this study. If you choose to participate, you may stop participating at any time; or refuse to answer any questions without prejudice, penalty, or risk of losing any rights and privileges that you otherwise have.

The researcher will at this time answer any additional questions that you may have.

Appendix D

Informed Consent Document

Analyzing the Effects of Inquiry-Based Instruction on the Learning of Atmospheric Science Concepts among Pre-service Teacher Education Students

> Principle Investigator: Dr. Joseph Stoltmam Student Inverstigator: Robert Ruhf, Ph.D. Candidate

Dear students:

My name is Robert Ruhf. I am a doctoral student with the Mallinson Institute for Science Education at Western Michigan University, and I am conducting a study on the learning of Earth science among pre-service teacher education students. You do not have to be an education student to participate. The findings of this research will provide the faculty of three departments with much needed insights related to the effectiveness of various courses. Your class has been selected to take part in this research, although your individual participation is entirely voluntary. If you choose to participate, you will be one of among approximately 200 total participants from several classes.

You will be asked to complete two tests. The first test will be given at the beginning of this semester. It should take approximately thirty (30) minutes to complete. You will be asked several questions related to key concepts in a particular area of Earth science, as well as real world applications of these concepts. You will be asked to answer all questions as best you can. This test will contain a cover page on which you will be asked to provide your name and to answer several questions about your personal background. You must include your name on the cover page, but *you may choose to not answer any or all of the background questions.* You will be tested again at the end of the semester in a similar manner. These two tests will be used to evaluate the growth in your level of understanding as a result of taking this course.

Approximately 10% of you will be randomly selected to participate in two interview sessions, the first of which will be conducted during the early part of this semester, and the second of which will be conducted at the start of the next semester. These sessions will not exceed 20 minutes each. All question asked during the interview sessions will relate to your understanding of Earth science. *You may choose to not participate in the interview sessions even if you complete the tests.* 

All of the information collected from you is confidential. That means that your name will not appear on any papers on which this information is recorded. The forms will all be coded, and I will keep a separate master list with the names of participants and the corresponding code numbers. Once the data are collected and analyzed, the master list will be destroyed. All other forms will be retained for at least three years in a locked file in Dr. Joseph Stoltman's office.

You may refuse to participate in this study. If you choose to participate, you may stop participating at any time; or refuse to answer any questions without prejudice, penalty, or risk of losing any rights and privileges that you otherwise have.

The researcher will at this time answer any additional questions that you may have.

Robert J. Ruhf Mallinson Institute for Science Education 3111 Wood Hall Western Michigan University Kalamazoo, MI 49008 Dr. Joseph Stoltman Department of Geography 3525 Wood Hall Western Michigan University Kalamazoo, MI 49008

The participant may also contact the Chair, Human Subjects Institutional Review Board (387-8293) or the Vice President for Research (387-8298) if questions or problems arise during the course of the study.

This consent document has been approved for use for one year by the Human Subjects Institutional Review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

Please print your name and indicate whether or not you are willing to participate in the interview sessions.

Name\_\_\_\_\_

"I am willing to participate in the interview sessions."yesno (You may still complete the tests even if you do not participate in the interviews.)	)
You must agree to participate in this study by signing the following statement:	

"I have read the purpose and requirements of this study and I agree to participate."

Consent obtained by (researcher's initials)\_\_\_\_\_ Date\_\_\_\_\_

Appendix E

Pretest Cover Page and Background Questions

# EARTH SCIENCE TEST

# **Personal Information**

Please note that this information will be destroyed after all tests and interviews have been coded with random numbers.)

What is your name?

What is your program of study? \_\_\_\_\_

Please answer "yes" or "no" to the following question: "I am willing to participate in two personal interview sessions \_\_\_\_yes \_\_\_\_no

(Please provide your contact information if you answered "yes.")

Phone number: (\_\_\_\_) \_\_\_\_\_ Email: \_\_\_\_\_

How often do you go to the library?

- a. \_\_\_\_\_ never
- b. \_\_\_\_\_ rarely, only when required
- c. \_\_\_\_\_ occasionally
- d. \_\_\_\_\_ frequently
- e. \_\_\_\_\_ as often as possible

Which of the following best describe your use of the computer?

- a. \_\_\_\_\_ I do not know how to use a computer
- b. \_\_\_\_ I know how to use computers, but I am uncomfortable with them.
- c. \_\_\_\_\_ I am comfortable using computers for basic work, such as word processing, surfing the Internet, and checking my email.
- d. \_\_\_\_\_ I use the computer often for many things.
- e. \_\_\_\_\_ I am a whiz at computer technology!

What is your GPA? \_\_\_\_\_

On average, how many class sessions do you typically miss per semester?

- a. \_\_\_\_\_0 to 1
- b. \_\_\_\_\_ 2 to 4
- c. \_\_\_\_\_5 to 7
- d. \_\_\_\_\_ 8 to 10
- e. \_\_\_\_ more than 10

Do you live on campus, or are you a commuter?

- a. \_\_\_\_\_ I live on campus
- b. \_\_\_\_\_ I am a commuter

What is your age? \_\_\_\_\_

Appendix F

The Pretest/Posttest
*Please choose the best response for each question. There is only one correct response per question.* 

- 1. \_\_\_\_\_ Air masses are classified based on which two criteria?
  - a. pressure and humidity
  - b. pressure and temperature
  - c. temperature and humidity
  - d. temperature and wind

You have been given a map of North America that highlights four locations lettered as A, B, C, and D. Use this map for Questions 2 and 3.

- 2. \_\_\_\_ Which of the following atmospheric conditions would most likely be found at position D?
  - a. warm and humid
  - b. dry and windy
  - c. warm and dry
  - d. cool and humid
- 3. \_\_\_\_\_ Air moving from which location is most likely to produce lake-effect snow as it moves over the Great Lakes during the winter months?
  - a. A
  - b. B
  - c. C
  - d. D

For Questions 4 and 5: You have been given a diagram illustrating the Earth's revolution around the sun. (Note that the Earth is in front of the sun at position B, and it is behind the sun at position "D.")

- 4. \_\_\_\_\_ What day of the year is it when the Earth is located at position A?
  - a. March 21
  - b. June 21
  - c. September 21
  - d. December 21
- 5. \_\_\_\_\_ How does the sunset time change in Michigan as the Earth moves from position A to C?
  - a. The sunset gradually occurs later as the Earth moves from position A to C.
  - b. The sunset gradually occurs earlier as the Earth moves from position A to C.
  - c. The sunset gradually occurs later until position B is reached; then the sunset gradually occurs earlier as the Earth moves from position B to C.
  - d. The sunset gradually occurs earlier until position B is reached; then the sunset gradually occurs later as the Earth moves from position B to C.

Please answer Questions 6 through 10.

- 6. \_\_\_\_\_ What is the primary reason for seasonal variations on Earth?
  - a. the distance the Earth is from the sun
  - b. the movement of storms along the jet stream
  - c. the tilt of the Earth on its axis
  - d. the interaction between the Earth's tilt and the Earth's distance from the sun
- 7. \_\_\_\_ What are the *minimum* criteria that will cause the National Weather Service to issue a severe thunderstorm "warning" for your county?
  - a. A storm is moving through your county that contains very heavy rain and/or dangerous cloud-to-ground lightning.
  - b. A storm is moving through your county that contains very large hail and/or strong damaging wind.
  - c. The criteria will vary from place to place. It is therefore important to find out from local officials what criteria are used in your area.
  - d. A thunderstorm is moving through your area that will last 20 minutes or longer.
- 8. \_\_\_\_ A tornado "watch" has been issued for your county. How should you interpret this?
  - a. A tornado is in your county and you must seek shelter immediately.
  - b. A tornado has been spotted nearby, but not necessarily in your county.
  - c. You should stay home, although you don't need to seek shelter yet.
  - d. No tornadoes have yet been spotted in your county, but you should take precautions for the possibility.
- 9. \_\_\_\_\_ If you are in a school when a tornado "warning" has been issued for your county, what is the first thing you should do?
  - a. Open all of the windows in the classroom in order to equalize the pressure.
  - b. Move to the hallway and lie flat with your head covered.
  - c. Seek safe shelter away from the school.
  - d. Seek shelter in the corner of the classroom that is furthest from the windows.
- 10. \_\_\_\_\_ What is a "cold front?"
  - a. a cold mass of air
  - b. circulation patterns around a cold low pressure center
  - c. the leading edge of a cold mass of air
  - d. a cold mass of air ahead of a sudden push of warm air

You have been given a weather map of the United States. Use this map to answer Questions 11 and 12:

- 11. \_\_\_\_\_ Which city on the map is experiencing the coldest temperatures?
  - a. New York
  - b. Seattle
  - c. Denver
  - d. There is no way to make this determination.
- 12. \_\_\_\_\_ If the low pressure center located between Denver and El Paso were to move northeast toward Chicago, what weather conditions would likely occur along the southern border of Michigan?
  - a. Cooling temperatures; increasing clouds and precipitation
  - b. Cooling temperatures; little or no clouds and precipitation
  - c. Warming temperatures; little or no clouds and precipitation
  - d. Warming temperatures; increasing clouds and precipitation

### Please answer Questions 13 through 16.

- 13. \_\_\_\_\_ What are the two most abundant gases in the Earth's atmosphere?
  - a. nitrogen and oxygen
  - b. oxygen and carbon dioxide
  - c. hydrogen and oxygen
  - d. oxygen and water vapor
- 14.\_\_\_\_ What happens to the air temperature and atmospheric pressure as elevation increases?
  - a. The air temperature decreases, but the atmospheric pressure increases.
  - b. Both the air temperature and the atmospheric pressure decrease.
  - c. Both the air temperature and the atmospheric pressure stay about the same.
  - d. The air temperature decreases, but the atmospheric pressure stays about the same.
- 15. \_\_\_\_\_ Imagine that you are camping on a mountain and you are boiling food in a pan over a fire. How does the boiling point temperature of water differ from what it would be if you were in your home at lower elevations?
  - a. The boiling point temperature of the water is higher at lower elevations.
  - b. The boiling point temperature of the water is higher on the mountain.
  - c. The boiling point temperature of the water is the same at both locations.
  - d. The boiling point temperature of the water has nothing to do with elevation.

- 16. \_\_\_\_\_ What kind of change occurs when condensation takes place?
  - a. A liquid changes to a gas.
  - b. A gas changes to a liquid.
  - c. A gas changes to water vapor.
  - d. Oxygen and hydrogen combine to form liquid water.

You have been given a diagram of water cycle. Use this diagram for Question 17:

- 17. \_\_\_\_\_ What natural process is occurring at C?
  - a. Water is evaporating into the air.
  - b. Gravity is pulling water droplets downward.
  - c. Condensation is taking place.
  - d. Visible water vapor is drifting through the air.

Consider the following situations for Question 18:

Situation 1: The temperature of the air above you is above the freezing point, but objects on the surface of the Earth are at or below the freezing point.

Situation 2: The air temperature is below the freezing point all the way from the ground level to the cloud base.

- 18. \_\_\_\_\_ What form of precipitation is falling in these situations?
  - a. Freezing rain is falling in Situation 1; snow is falling in Situation 2.
  - b. Sleet is falling in Situation 1; freezing rain is falling in Situation 2.
  - c. Sleet is falling in both situations.
  - d. Freezing rain is falling in Situation 1; sleet is falling in situation 2.

Please answer Questions 19 through 23.

- 19. \_\_\_\_\_ What name is given to solid particles or liquid droplets that are small enough to be suspended in the air?
  - a. emissions
  - b. crystalline nuclei
  - c. particulate pollution
  - d. particulate matter
- 20. \_\_\_\_\_ Which of the following statements about air pollution is true?
  - a. Human activities are responsible for all forms of pollution that are harmful to human health.
  - b. Air pollution is generally not a factor inside buildings or homes.
  - c. Carbon dioxide and pollen are sometimes considered to be pollutants.
  - d. Current levels of air pollution are so high that there is little that can be done to reduce the problem.

- 21. \_\_\_\_\_ On hot and humid summer days, an "Ozone Action Day" is sometimes declared. Why is it recommended that you not fill your car's gasoline tank on such days?
  - a. Gasoline prices are usually higher on Ozone Action Days.
  - b. Hot and humid weather places stress on the machinery in gasoline pumps.
  - c. Filling your gasoline tank forces harmful fumes into the air.
  - d. Research has demonstrated that humidity levels can be reduced if people will fill their gasoline tanks less often.

Some of the diagrams that you were given for this test were reproduced with permission from the following book:

Denecke, Edward J. (2003). *Let's Review: Earth Science: The Physical Setting*, 2<sup>nd</sup> *Edition*. Hauppauge, NY: Barron's Education Series Inc.

Appendix G

A Sample Classroom Observation Record

### **Observational Sheet for GEOG 105:**

Instructor:[Name removed] Date	:February 7, 2005
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Observer: <u>Robert Ruhf</u>

9:00 a.m. – Instructor says, "Good morning, everybody!"

9:01 a.m. – Instructor talks about the Superbowl; then introduces a guest.

9:02 a.m. – Instructor says, "Get into groups of three." Students move around. They're not moving very quickly.

9:03 a.m. – Instructor begins to group the students who have not yet gotten into a group.

9:04 a.m. – Instructor hands out a sheet. Instructor then starts to explain it. It contains information about the Beufort wind scale, and what happens to a house with various wind strengths; it also tells how various wind speeds will affect waves on bodies of water.
9:05 a.m. – Instructor continues to explain the hand-out.

9:06 a.m. – The instructor explains to the students that the instructor and the guest are going to show various video clips and students will have to use the hand-out to identify the number on the wind scale. Instructor reads "Module objectives" that are on the overhead.

9:07 a.m. – Video one: waves on L. Michigan near South Haven. Students write scale number.

9:08 a.m. – Instructor shows the video again. Students continue to guess at scale number.

9:09 a.m. – Instructor asks if everybody is ready for second one. Silence. Instructor repeats the question. Chorus: "Yes." Second video: Gulf of Mexico, Texas coast.

9:10 a.m. – Third video: Austin Lake. Students come up with Beufort number.

9:11 a.m. – Fourth video: flags on the campus of WMU. Students write Beufort number.

9:12 a.m. – Fifth video: flags in Frankenmuth. Students write Beufort number.

9:13 a.m. – Sixth video: campus flags again. Students write Beufort number.

9:14 a.m. – Instructor asks, "Are trees damaged by wind in Michigan? Write your answer, and if you say yes, tell me what type of damages they experience." Students write.

9:15 a.m. – Instructor asks, "What other damages are linked to tree damage besides wind? Write it down."

9:16 a.m. - A student, "What was the question?" Instructor repeats it. Students write.

9:17 a.m. – Seventh video: trees on WMU's campus. Students write Beufort number.

9:18 a.m. – Eighth video: trees in the same area. A student shouts out, "They're the same!" Instructor says, "No, they're not!" Different wind speed. Students write response.

9:19 a.m. – Ninth video: winds stronger; same trees. Students write response.

9:20 a.m. – Tenth video: campus trees; winds totally calm. Students write response.

9:21 a.m. – Lecture asks, "Is it possible to sail against the wind?" A student quickly says, "Yes." Instructor says, "Write it down and explain your answer!"

9:22 a.m. – Lecture asks, "Is friction experienced by sailboats more or less than airplanes, and explain your answer." Students write.

9:23 a.m. – Students continue to write.

9:24 a.m. – Lecture asks, "What is the physically faster speed that a sail boat can travel?" A student shouts out, "As fast as the wind." Instructor says, "Write it down!!!" Students write.

9:25 a.m. – Instructor asks, "What does it mean when a sailboat is going on plane?" A student shouts out an answer again. Instructor says, "Does everybody understand the concept of 'write it down?" Students write.

9:26 a.m. – Instructor asks, "What effects on humans do we worry about with wind and temperature?" Students write.

9:27 a.m. – Instructor asks, "Do certain events in the world affect the winds in Kalamazoo, such as oil spills and volcanic eruptions?" Students write.

9:28 a.m. – Students write.

9:29 a.m. – Students write.

9:30 a.m. – Instructor asks what is fundamentally difficult when it comes to Kalamazoo cleaning up the air pollution problem that we have. Students write.

9:31 a.m. – Students write.

9:32 a.m. – Instructor says, "Let's go back and see what you did?" Instructor asks what the various groups put for the first video. All groups give their responses. The guest tells them what the correct answer is.

9:33 a.m. – Same format as 9:32 for remaining videos.

9:34 a.m. – Same format as 9:32 for remaining videos.

9:35 a.m. – Same format as 9:32 for remaining videos.

9:36 a.m. – Instructor asks, "Are trees damaged by winds in Michigan?" Students: "Yes." Instructor says, "Give examples." Students give examples, like "branches break."

9:37 a.m. – Instructor asks about other factors linked to treed damage. Students: ice, storms, etc.

9:38 a.m. – Instructor asks, "How can you sail against the wind?" A student knows and explains. Instructor asks about airplanes and friction. A student says something about weight. Instructor asks, "Is friction about weight?"

9:39 a.m. – A student responds to the instructor's weight question. Instructor confirms student's response.

9:40 a.m. – Instructor lectures on calm winds in the doldrums; boats getting stuck; no wind.

9:41 a.m. – Instructor lectures.

9:42 a.m. – Instructor lectures.

9:43 a.m. – Instructor asks about "going on plane." Students shout out various responses.

9:44 a.m. – Instructor lectures about the "year without a summer" in the 1800's.

9:45 a.m. – Instructor asks about pollution in Kalamazoo. A student says that most of our pollution problem comes from Chicago, and we can't control Chicago.

9:46 a.m. – Instructor lectures about Canada's problem with United States pollution. Instructor jokes, "They compensate by sending us all of their trash." The class laughs.

9:47 a.m. – Instructor asks students to write feedback to this module (exercise) for the instructor and the guest. Instructor tells them that they could be tested on this exercise.

9:48 a.m. – Instructor asks students to pass their written feedback comments to the middle of the aisle when they are done, and the instructor and the guest will collect them. Then the instructor says, "We're getting out two minutes early!"

Appendix H

A Sample Classroom Observation Record for the Co-Observer

### **Observational Sheet for GEOG 105:**

Instructor:	[Name removed]	 Date:	<u>February 7, 2005</u>

Observer: (2)

9:00 a.m. – Instructions on overhead  $\rightarrow$  write down a question from the last chapter; instructor chatting w/students abut non-class info.

9:01 a.m. – "Good morning!" Instructor asks about weekend & Super Bowl; tells student there is 1 <sup>1</sup>/<sub>2</sub> minutes left to turn in homework.

9:02 a.m. – Introduces guest in classroom; asks students to get into groups of three.

9:03 a.m. – Students organizing into groups; instructor helps to divide students (calling several students by name...)

9:04 a.m. – Instructor explaining that students need to have a piece of paper out for answers. Instructor passes out sheets to class; instructor explaining sheet that was passed out.

9:05 a.m. – Instructor explaining worksheet; instructor question – when use knots? Student response (many): sailing;

9:06 a.m. – Instructor explaining video will come and students need to use worksheets to identify wind; instructor explaining objectives for module.

9:07 a.m. – Instructor explains objectives; student question – everyone needs to write out answers? Instructor answer – no; instructor explaining video clips and how video will come...

9:08 a.m. – Students conversing w/group partners. Video clip plays; student question – Did you take video clip? Instructor response – yes. Instructor question – see again? Student response – no response; instructor explaining: write down wind scale number.

9:09 a.m. – Students conversing w/group partners. Instructor – helps to get late students into groups; instructor question – ready for #2; instructor question: want to see again? Student response – yes.

9:10 a.m. – Students conversing w/group partners. Video plays... Students talking w/partners to determine answers.

9:11 a.m. – Students conversing w/group partners. Student question – where is lake? Guest answers and explains. Instructor explaining – next clips are of flags.

9:12 a.m. – Students conversing w/group partners. Clips play... Instructor explaining: Why Chicago called "windy city."

9:13 a.m. – Students conversing w/group partners. Clip plays. Instructor question – need again? Student response: once more.

9:14 a.m. – Students conversing w/group partners. Clip plays (flag 3). Instructor question – asks a group if they are actually working together;

9:15 a.m. – Students conversing w/group partners. Instructor question – got this one? Student response: yes. Instructor question – Are trees damaged in Michigan? Instructor explaining  $\rightarrow$  Write down answers on sheet (students discussing...).

9:16 a.m. – Students conversing w/group partners. Students interacting; instructor question – everybody got it? Instructor question – other factors linked to tree damage besides wind (write it down)... Student question – asks instructor to repeat question.

9:17 a.m. – Students conversing w/group partners. Instructor explaining next clips; tree clips  $\rightarrow$  first one; instructor question – again? Student response – no. Instructor question – have an answer?

9:18 a.m. - Students conversing w/group partners. Next clip; ...explains where clip taken...

9:19 a.m. – Students conversing w/group partners. Students interacting...; instructor explaining: strong winds happen in Kalamazoo. Instructor question – everyone have answer? Next clip...

9:20 a.m. – Students conversing w/group partners. Instructor question: everyone have answers? Instructor talking w/guest; instructor explaining  $\rightarrow$  now we want to think about how we can use wind.

9:21 a.m. – Students conversing w/group partners. Instructor question – Possible to sail against wind? Why/Why not? Student response – discussing & writing down answers; students discussing.

9:22 a.m. – Students conversing w/group partners. Students interacting; instructor question – everyone have answer? Student response – yes. Instructor question – asking about friction  $\rightarrow$  explains what type of answer to write.

9:23 a.m. – Students conversing w/group partners. Students discussing... Instructor question – everyone ready. Student response – yes.

9:24 a.m. – Students discussing in groups. Instructor question – asking about sailing & wind... Student response – one answers out loud... Instructor explaining – "Write it down..."

9:25 a.m. – Students discussing in groups. Instructor interacting w/students; instructor question – what does "going on plane" mean? Instructor explaining – write it down; students responding.

9:26 a.m. – Students discussing in groups. Instructor question – relates to wind chill; what other things related to wind and temperature? Students discuss; instructor explaining – write it down.

9:27 a.m. – Students discussing in groups. Instructor question – everyone ready? Student response: yes; instructor question – do events around the world affect Kalamazoo, how? Students discussing.

9:28 a.m. – Students discussing in groups. Student question – asks instructor to clarify question & asks about tsunami (just b/t instructor and student).

9:29 a.m. – Students discussing in groups. Instructor question – everyone have answer? Student response – not yet; student question – what is this for? Instructor explaining – they help talk about wind; trying new techniques.

9:30 a.m. – Students discussing in groups. Instructor question – last question; question about Kalamazoo being "non-attaining" in regards to air pollution...

9:31 a.m. – Students discussing in groups. Instructor question – what is hard for Kalamazoo county and wind... Students discussing.

9:32 a.m. – Students discussing in groups. Instructor chatting w/students about sunrise. Instructor – reviewing video clips questions. Instructor calls on individual groups.

9:33 a.m. – Reviewing questions from before... Instructor explaining – should be "4-5." Instructor question – second clip  $\rightarrow$  calls on individual groups and come to consensus; instructor question – 3<sup>rd</sup> clip (calls on groups).

9:34 a.m. – Reviewing questions from before... Instructor question – flag clip #1  $\rightarrow$  calls on individual groups (uses student names). Students come to consensus; instructor question – flag #2 (calls on groups).

9:35 a.m. – Reviewing questions from before... Instructor question – flag #3  $\rightarrow$  asks students to call our #'s; instructor question – tree #1 (call out #'s). Instructor question – Tree #2 (call out #'s).

9:36 a.m. – Reviewing questions from before... Student question – about why only whole #; instructor question – Tree #4  $\rightarrow$  Tree #5  $\rightarrow$  Instructor question – Trees damaged? Student response –yes. Instructor question – how? Student response – volunteer simple response.

9:37 a.m. – Reviewing questions from before... Instructor question –any others? Talking about types of tree damage. Instructor question – other factors? Student response – randomly call out answers.

9:38 a.m. – Reviewing questions from before... Instructor question – friction question? Student response – random answers volunteered.

9:39 a.m. – Reviewing questions from before... (Guest chimes in...) Instructor question – friction – boats & planes. Student response – various; instructor asks one student to repeat answer.

9:40 a.m. – Reviewing questions from before... Instructor question – directs question to one student. Student response – gives correct answer. Instructor explaining  $\rightarrow$  winds & currents in clockwise pattern...

9:41 a.m. – Reviewing questions from before... Instructor explaining – explaining sailing when discovering "New World;" explaining horse latitudes.

9:42 a.m. – Reviewing questions from before... Instructor explaining – horse latitudes & doldrums; ... student question about sailing in those latitudes.

9:43 a.m. – Reviewing questions from before... Instructor question – "going on plane." Student response – gives answer. Instructor explaining – explains on student response. Instructor question – next? Student response – volunteer responses...

9:44 a.m. – Reviewing questions from before... Instructor question – world events? Student response – yes. Instructor response – why? Student response – b/c wind can carry things. Instructor explaining – expands on response...

9:45 a.m. – Reviewing questions from before... Instructor explaining – "year w/o summer," Student question – how cold? Instructor response – about 20 degrees colder; \*Guess chimes in.

9:46 a.m. – Reviewing questions from before... Instructor question – Kalamazoo pollution... Student response – Chicago. Instructor question – asks about Chicago; student response – various. Instructor response – expands on answers.

9:47 a.m. – Reviewing questions from before... Instructor question – any questions; instructor explaining – tells students to get out  $\frac{1}{2}$  sheet of paper; instructor asks students to write opinion about activity on sheet  $\rightarrow$  feedback...

9:48 a.m. – Student question – how many turn in? Instructor response – one. Instructor explaining – reminds students they could have test questions from this module.

9:49 a.m. - Instructor explaining - pass sheets in when finished...class dismissed...

Appendix I

Instructor Informed Consent Document

Analyzing the Effects of Inquiry-Based Instruction on the Learning of Atmospheric Science Concepts among Pre-service Teacher Education Students

> Principle Investigator: Dr. Joseph Stoltmam Student Inverstigator: Robert Ruhf, Ph.D. Candidate

Dear instructor:

My name is Robert Ruhf. I am a doctoral student with the Mallinson Institute for Science Education at Western Michigan University, and I am conducting a study on the learning of atmospheric science concepts among pre-service teacher education students. The findings of this research will provide the faculty of two departments with much needed insights related to the effectiveness of various courses. Your class has been selected to take part in this research, although your individual participation is entirely voluntary.

Students in your class will be asked to complete two tests. The first test will be given at the beginning of this semester. It should take approximately fifteen (15) minutes to complete. They will be asked several questions related to key concepts in atmospheric science, as well as real world applications of these concepts. They will be tested again at the end of the semester in a similar manner. These two tests will be used to evaluate the growth in their level of understanding as a result of taking your course.

Approximately 10% of your students will be randomly selected to participate in an interview session which will be conducted at the start of the next semester. Each session will not exceed twenty (20) minutes. All question asked during an interview session will relate to atmospheric science content. Students may choose to not participate in the interview session even if they complete the tests.

The researcher will attend and observe all of your lecture and lab sessions related to atmospheric science content. Observations related to instructional strategies employed by you and your teaching assistants will be written. This will be done in order to determine how much of your strategies are based on traditionally-based pedagogical strategies, and how much are based on inquiry-based pedagogical strategies. The researcher will write a general statement *at least* once per minute summarizing what is happening in the class. Possible observations include, "the instructor is lecturing" (a traditionally-based strategy), "a student has asked a question and the instructor has responded by giving a direct answer" (an inquiry-based strategy), "a student has asked a question but the instructor has responded by asking the student another question" (an inquiry-based strategy), "students are engaged in a hands-on activity in which they were directly told what to do" (a traditionally-based strategy), and "students are engaged in a hands-on activity in which they were told to develop their own solution to solving a problem" (an inquiry-based strategy). Percentages will be calculated for each course as to how many minutes were dedicated to traditionally-based strategies and how many minutes were dedicated to inquiry-based strategies.

You may refuse to participate in this study. If you choose to participate, you may stop participating at any time without prejudice, penalty, or risk of losing any rights and privileges that you otherwise have.

The researcher will at this time answer any additional questions that you may have.

Robert J. Ruhf	Dr. Joseph Stoltman
Mallinson Institute for Science Education	Department of Geography
3111 Wood Hall	3525 Wood Hall
Western Michigan University	Western Michigan University
Kalamazoo, MI 49008	Kalamazoo, MI 49008

The participant may also contact the Chair, Human Subjects Institutional Review Board (387-8293) or the Vice President for Research (387-8298) if questions or problems arise during the course of the study.

This consent document has been approved for use for one year by the Human Subjects Institutional Review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

Please print your name below.

Name\_\_\_\_\_

You must agree to participate in this study by signing the following statement:

"I have read the purpose and requirements of this study and I agree to participate. The researcher may attend all of my lecture and lab sessions related to atmospheric science content. He may write any observations related to instructional strategies employed by myself and my teaching assistants."

Signature	Date
<i>c</i> <u> </u>	

Consent obtained by (researcher's initials)\_\_\_\_\_ Date\_\_\_\_\_

Appendix J

A Sample Interview Session

#### Student: 91 (Geography 190, Fall 2004)

(Underlined questions indicate a new line of questioning, or a new topic.)

Bob: All right, let's get started with a basic question about an air mass. What's an air mass? Let me ask you that question first of all.

S-91: Um...like...

- Bob: If I were to...if this were an exam question: "Define an air mass." What would you write down?
- S-91: Um...particles grouped together in...tested area.
- Bob: Particles grouped together in a what area?
- S-91: Like a...I don't know. Um...
- Bob: What do you mean by "particles?"
- S-91: Like an air mass. Do you mean like high and low pressure air masses? Or...
- Bob: Well, any time in class, have you ever heard the phrase "air mass?"
- S-91: Well, every time we talk about air masses, they're like low pressure air masses moving into, like, high pressure air masses, and...and then we talked about air masses as far as the particles that are involved in air.
- Bob: What particles are involved?
- S-91: Like oxygen and carbon dioxide.
- Bob: So you said that there were high pressure air masses and low pressure air masses. What are those?
- S-91: Right. Um...high pressure is associated with bad weather. Low pressure is associated with good weather as far as like, uh...
- Bob: So low pressure is "good" weather...
- S-91: High's with bad. High pressure is like, um, air pushing down. Low pressure is the air rising.
- Bob: So the storms we've been getting recently, say for example the snowstorm we had last week, was that a high pressure or a low pressure? (Note: The date for this interview is December 6, 2004. There was a snowstorm on the night of December 1, 2004 through the early morning hours of December 2, 2004)

S-91: High.

Bob: How would you know? Why is it a high?

S-91: (silence)

- Bob: What is it about a high pressure that would cause an event like a storm?
- S-91: Like...pushing into low pressure zones, like high pressure systems pushing into low pressure zones.
- Bob: What happens when...okay...well, what happens when air gets pushed into a low?

S-91: It causes wind.

Bob: What's a front?

- S-91: Like, the beginning, the crest of the air mass.
- Bob: The beginning...? What do you mean by the "crest" of the air mass?
- S-91: Um...the front of it. The...
- Bob: (Bob hands the student a piece of paper with an "H" and an "L" drawn on it.) So, on here draw what you think is happening around these highs and lows with wind direction, type of weather, and anything that you know about fronts.
- S-91: Um...I don't understand what you want me to draw, though, as far as...
- Bob: Well, okay, you were mentioning what type of weather was associated with highs and lows, and you were saying that the air was moving from the high to the low...

S-91: Right.

- Bob: So I'm asking you to draw what the air motion is like around these highs and lows, and if you can show me where the fronts are in relation to those highs and lows.
- S-91: Um...I was just talking about what the wind would be like.
- Bob: Okay, what would the wind be like?
- S-91: Like, off a lake, in the daytime, there's low pressure coming off the sand, and high pressure over the water. You have, um, your sea winds coming off the water, and at night it reverses.
- Bob: That's like a sea breeze...
- S-91: A sea breeze and a land breeze.
- Bob: But what about high and low pressure systems that move across the United States?
- S-91: I guess I don't know.
- Bob: Uh...what's the circulation of air like around a high?
- S-91: Like...like as far as... (See the first diagram below for what the student drew.)
- Bob: What's the circulation of air like around a low?
- S-91: Like this... (See below for what the student drew.)



- Bob: So the air is...is the air...?
- S-91: Counter-clockwise and clockwise.
- Bob: Okay. Where does the air move in-between the high and the low?
- S-91: What do you mean?
- Bob: What's the air like in here... (Bob points to the blank space between the "H" pressure and the "L" pressure on the student's drawing.) ...between this high and low?
- S-91: I have no idea.
- Bob: Okay. Um...where does the air come from that influences the weather in Michigan? (Note: Bob tries to return to a discussion of air masses.)
- S-91: The west.
- Bob: Okay. Is it possible to have air come out of the south or the north?
- S-91: Yeah, I suppose.
- Bob: How is that possible?
- S-91: Um...the curve of the earth, like how the winds shift.
- Bob: How do the winds shift?
- S-91: I have no idea.
- <u>Bob:</u> Um, let's, uh, let's talk about, um, why it's colder in January or December, in Michigan, than it is in June or July. What can you tell me about that?
- S-91: Well, the tilt of the earth, direction of sunlight, uh, reflection, and, um, number of daylight hours.
- Bob: Okay. Can you give me an illustration? Draw me...explain to me with a model, a drawing of why it's colder in January? Relationship of the earth to the sun that would explain why it's colder in December and January. (See the diagram below for what the student drew.)



- S-91: Well...tilted...um...more so that the southern hemisphere is in more direct comparison to the sun than the northern hemisphere...the sun is more direct in direct to the southern hemisphere in...
- Bob: In January?
- S-91: In January and December than in...
- Bob: Where's the equator?
- S-91: (silence)
- Bob: Okay, label which one is January. (For some reason, Bob's mind got stuck on "January" instead of focusing on "December 21" for the solstice. This may have created some confusion for the student.)
- S-91: This would be January up here. (The student picks the diagram on the top, which is actually the position for September 21.) (*The student makes more comments, but they are inaudible.*)

Bob: Okay...

- S-91: No! January is supposed to be right here...isn't it? (**The student then points to the correct drawing on the right side of the diagram.**) This, like, basically we did, um, in the class through our group presentations. Like, we did, um...somebody did a presentation on this, and that's what I'm trying to recall right now, but...cause this...when we talked about... I don't really remember like the whole tilt of the earth. I just remember that, um...the seasons are because of the different things, and we had a lab on each thing. So the tilt of the earth thing, we were looking at the maps on-line.
- Bob: What's the biggest factor for seasons?
- S-91: Tilt of the earth. So direct sunlight.
- Bob: So explain this drawing right here. (Bob points to the student's drawing of the earth-sun relationship.)
- S-91: Okay. Um...
- Bob: Have you had earth science in high school?
- S-91: No. This is my first one. I do feel like I understand it the way he explains it, but, um...I can't tell *you* how I understand it! Like, okay! The sun is here, right? (**Student points to the center of the diagram.**) I'm better at objects! And you got your planet going around it, and in the summertime the earth is shifted so that the northern hemisphere, our area, is in, like, direct comparison to the sun. As the sun goes around, it tilts, like, more and then we have our next season where we're having the most daylight shifting hours as far as...um, or more daylight shifting hours, like, in the winter it's, like...in the winter it equals out as far as negative/positive, as far as daylight hours, than in the summer. And it gets, because of the tilt of the earth and daylight hours...it gets farther away from the sun in the fall. And then in the winter, it's the farthest away from the sun.

Bob: Okay, you-

- S-91: No, wait! Not "away from the sun!" Like, the *tilt* of the earth is!
- Bob: So the tilt doesn't change?
- S-91: No. So the rotation...

- Bob: Where's the sun's direct rays here? (Bob points to the drawing for December 21. However, the student's answer seems to indicate that the student misunderstood and thought Bob was pointing to one of the equinoxes.)
- S-91: They're more...they're moving down toward the equator more, and then in our winter they're more in the southern hemisphere.

Bob: Okay. Let's change the...What's a severe thunderstorm warning?

- S-91: Um...means that a thunderstorm...has the...a warning is...it has the potential of becoming...to having severe rain or damaging winds.
- Bob: So what's a severe thunderstorm "watch?"
- S-91: Oh, *that's* the potential! "Warning" is when it's, like, there! I'm sorry. I'm sorry.
- Bob: So if you have a warning, what types of things do you have in that thunderstorm that causes them to issue a warning?
- S-91: Uh, probably high rain, high winds, um...a bad storm. Lots of rain.
- Bob: How much rain does there have to be? Can you get heavy rain and not have a severe thunderstorm warning?
- S-91: Yeah. Yeah, you can definitely have that. I guess a thunderstorm is just the wind and the electric activity of lightning.
- Bob: Can you have lots of lightning and them still not issue a severe thunderstorm warning?
- S-91: Yes.
- Bob: So what's the criteria for a "regular" thunderstorm and a "severe" thunderstorm?
- S-91: The intensity and maybe the possibility of more danger, and damage.
- Bob: Damage from what?
- S-91: Wind. Flooding.
- Bob: Alright. Let's talk about tornadoes a little bit. If you're in a school, and there's a tornado warning, what do you do?
- S-91: Open the windows. Go to the area farthest away from windows, like in the hallways where you're not going to have as much blowing around and breaking. And cover your head with something hard, the back of your head. To protect yourself from debris.

Bob: Why do you open the windows?

S-91: When I was in 6<sup>th</sup> grade, we were driving back from Cedar Point, and it got, like, completely black and it started down pouring, and it went from just, like, beautiful nice hot day at Cedar Point to being, like, horrible rain and everything! So I just remember that we all shut the windows and everything, so it was raining so hard. And the bus driver couldn't see at all, so she pulled into a rest stop and we parked between a semi and a delivery truck, and...so we...she says, you know...there's screaming...we turn on the radio and everyone's screaming, and you can hear trees breaking. It was like trucks driving through! It was the craziest sounds ever! And we looked behind us and you could see this tornado coming out of the field behind the rest stop. And so the bus driver just starts screaming at everyone, "Get under the seats! Get

under the seats! Get under the seats!" And we all climbed under our seats, holding on to our seats, and the bus, like, picked up and was, like, trying to move! Like, it was hitting the side of the semi-truck! And then all of the emergency windows on the bus blew off the bus, and the emergency, like, the exit thing on the top of the bus shot off the bus! And the bus flew down...dropped to the ground, and the semi-truck next to us fell over, and then we all just sat there shaking and everything. And the whole point of the story is all the windows shot open equalizing some of the pressure and letting it in. And that's when our bus had dropped. Which I don't know if that's...

Bob: It's actually the force of the wind that's causing that.

S-91: (*This next sentence was said with a sarcastic tone of voice.*) So, the bus driver was really reassuring! She's screaming as we are all under our seats, "We're all going to die!"

Bob: Ha ha.

- S-91: With a bunch of sixth graders!
- Bob: Ha ha. She was? Ha ha.
- S-91: She's screaming at the top of her lungs, "We're all gonna' die! We're all gonna' die!" And, uh...
- Bob: You're all in sixth grade! Ha ha.
- S-91: We're in sixth grade. And we're all under our seats, like, confused and upset. And then we had to...she's like...and then it stopped and we were running into the rest shelter down into the basement. We were down there for like four hours. And, uh, in the series of four hours, seven tornadoes passed through the area. And the roof was blown off the rest shelter...the rest area...like, huge damages! We had to have another bus drive down and get us that next day because our bus was completely ruined. A tree had, like, blown over on top of it. And...
- Bob: You had to stay at the rest stop overnight?
- S-91: Well, no, they took us at like 4:00 in the morning. They took us to a...they took us to a ...area, like, a hotel a mile away, like, at 4:00 in the morning. And then we got picked up at like 10:00 the next day.

Bob: Hmmm.

- S-91: So it ended up being a really expensive trip for the school, too. Because it was, like, one of those "Keep-kids-active-in-the-summertime" things. So your parents would, like, pay to take...
- Bob: That's like the "storm chasing" trip!
- S-91: Yeah! Ha ha. It was scary. It was really scary for us, being a sixth grader, but...
- Bob: What did you say to the teacher afterwards? Anything?
- S-91: The bus driver? No, we didn't really say any-
- Bob: Er, the bus driver!
- S-91: Yeah, we didn't really say anything to her. But, like, we told our parents and stuff. And, like, the people that contacted the newspaper said that...quoted that she was being inappropriate, and stuff. Because all the students had told their parents that she was screaming, "We're all gonna' die!"

#### Bob: Let's change the subject again. Ever been up into the mountains?

S-91: Yes.

Bob: Okay, what happens to your ears?

- S-91: As you go up, they seem to, like, pop because of the pressure, like, um, pushing on your eardrums.
- Bob: What happens to the pressure that caused your ears to pop?
- S-91: Because there's not as much air pushing down on you.
- Bob: Okay. Um...can you illustrate that with a drawing?
- S-91: Sure. (See the diagram below for what the student drew.)



- S-91: Um...here's your hill. And here you have all of this pressure pushing down on your little person. (Student points to the arrow above the person on the left side of the drawing.)
- Bob: Okay.
- S-91: And when you're up on this up here, you only have this much pressure pushing down on you. (The student points to the arrow above the person on the right side of the drawing.)

Bob: Okay. What's a cloud? How do you get a cloud?

- S-91: Condensation...(inaudible)...at dew point when the temperature and...relative dew point...(inaudible)
- Bob: How does that happen?
- S-91: Um...humidity's involved in here somewhere, too. The water rises, like condensation either in sublimation or condensation depending on whether it's a gas or a form. And when it reaches a certain level in the sky where the temperature is equal to the dew point causes it to take on new form or...

Bob: What's the new form?

S-91: A cloud.

- Bob: What form is the cloud?
- S-91: It is...I'm not sure. Sorry! Ha ha.
- Bob: So you're saying that it's water in some form.
- S-91: Right.
- Bob: What are the forms that  $H_2O$  can be in?
- S-91: Gas. Liquid. Or it can be solid if it's ice, but...
- Bob: So what form is a cloud in?
- S-91: A gas form.
- Bob: Can you see it?
- S-91: Yes.
- Bob: Okay. What about before it forms a cloud? What form is it in?
- S-91: (silence)
- Bob: Because the cloud forms up there. Where's the water in the cloud come from before it forms a cloud?
- S-91: Comes from the ground...er, the lakes.
- Bob: The lakes. So how does it get from the lake to the cloud?
- S-91: Um, it evaporates into a gas, and, because of convection, particles are carried upward because they're less dense.
- Bob: Okay, why are they less dense? What happens in convection?
- S-91: The particles heat up.
- Bob: How do they heat up?
- S-91: From the ground source.
- Bob: How does the ground get heated?
- S-91: From the sunlight.
- Bob: And then what happens?
- S-91: And then it rises and they form the cloud and it reaches the dew point where it becomes stable.
- Bob: So how do you reach the dew point?
- S-91: Temperature...and then it forms the cloud and when they become colder, then the dew point, they go into a liquid form and fall... (*inaudible*)

Bob: Okay, so the precipitation is the liquid form, but a cloud is still a gas form. Is that what you are saying?

- S-91: I don't know. I was just on an airplane yesterday, and we were flying all the way through clouds. I didn't see any water being stuck, like, to the window.
- Bob: How is it you can't see the water vapor here, but you can see it in the cloud? If they're both water vapor, how is it that you can see one but not the other?
- S-91: I'm not sure. Maybe it's just the... I don't know. There has to be some kind of water vapor in it that makes it visible. I don't know.

#### Bob: Are you familiar with ozone action days?

S-91: Kind of. Someone told me on campus last year that it was one of those days, and I was just, like, "Oh! Okay!" She said you weren't supposed to get gas today, or something like that. I said I was going to get gas, and she said, "You're not supposed to today." You're supposed to try to keep all of the fumes out of the air for one day because it's certain...something with radiation that makes it more...it's more impacting, or something like that, like, on that day because of some reason. They didn't really know how to explain it that well. It's just that we weren't supposed to because it was worse than on other days.

Bob: Like, what was worse?

- S-91: Like, it would effect it more because...
- Bob: Effect what? What's "it?"
- S-91: The ozone, because it didn't have some protective layer, or something on that day for some reason.
- Bob: It would effect the ozone where? Where's the ozone at that's being effected?
- S-91: Very high. Um...
- Bob: How is adding fumes to the air down here going to effect the ozone up there?
- S-91: They're gonna' float up.
- Bob: How are they gonna' float up?
- S-91: Through convection. Like that horrible "rice" lab. (The student is referring to the very first lab done in GEOG 190 where they put rice in boiling water and watch it circulate in a convective cell.)
- Bob: Oh! You didn't like that rice lab?
- S-91: Well, I just think, like, the rice is confusing for a lot of people because it isn't the rice that's actually convecting. It's the water! So the rice is just kinda' there so you can see it. That makes it confusing.
- Bob: That's all the questions I have.
- S-91: Okay.
- Bob: Thank you very much.
- S-91: You're welcome.

Appendix K

A Comparison of the SAMPI Lesson Observation System Ratings Assigned for the Researcher's Observations and for the Co-Observer's Observations

	2	l-Jan-	05	7	-Feb-(	)5	11-Feb-05		
Classroom observer	1	2	d	1	2	d	1	2	d
Implementat	ion c	of th	e les	son	que	stion	IS		
Instructor confidence	6	6	0	7	7	0	6	6	0
Teacher-student interaction	2	3	1	5	6	1	1	2	1
Classroom management	2	3	1	5	6	1	1	2	1
Pace of the lesson	4	4	0	7	7	0	4	4	0
Student-student interaction	1	1	0	6	6	0	1	1	0
Reflection on the lesson	1	1	0	5	5	0	1	1	0
Wrap-up of the lesson	1	1	0	5	5	0	1	1	0
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	2	3	1	6	6	0	1	2	1
Portrayal of subject matter	1	1	0	6	5	1	1	1	0
Instructor conpetance	7	7	0	7	7	0	7	7	0
Connection to other lessons	2	2	0	2	2	0	2	2	0
Connection to other subjects	2	2	0	2	2	0	2	2	0
Application to the real world	2	2	0	5	5	0	2	2	0
Use of abstractions	6	5	1	7	7	0	6	6	0
Classro	om	cultu	ire q	uest	ions				
Active participation of students encouraged	2	4	2	7	7	0	2	2	0
Teacher's respect for students' ideas	2	4	2	5	6	1	1	2	1
Students' respect for other students' ideas	1	1	0	7	7	0	1	1	0
Students encouraged to generate ideas	3	3	0	6	6	0	3	4	1
Teacher-student collaborative relationships	1	1	0	6	5	1	1	1	0
Student-student collaborative relationships	2	3	1	4	6	2	1	2	1
(	Overall ratings								
Overall implementation rating	2	3	1	6	6	0	2	2	0
Overall content rating	4	4	0	5	5	0	4	4	0
Overall culture rating	2	3	1	6	6	0	2	2	0
Overall summary rating	3	3	0	6	6	0	2	3	1

# Co-Observation Ratings for the Geography 1050b Lecture Section

	19	9-Jan-	05	20	5-Jan-	05	2-Feb-05		05
Classroom observer	1	2	d	1	2	d	1	2	d
Implementat	ion c	of th	e les	son	que	stion	IS		
Instructor confidence	5	5	0	5	5	0	5	5	0
Teacher-student interaction	3	3	0	3	4	1	3	2	1
Classroom management	4	4	0	4	5	1	4	3	1
Pace of the lesson	4	4	0	4	4	0	4	4	0
Student-student interaction	4	2	2	5	6	1	4	3	1
Reflection on the lesson	3	3	0	3	3	0	3	3	0
Wrap-up of the lesson	1	1	0	1	1	0	1	1	0
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	4	3	1	3	4	1	4	2	2
Portrayal of subject matter	4	4	0	4	4	0	4	4	0
Instructor conpetance	5	5	0	5	5	0	6	5	1
Connection to other lessons	1	1	0	1	1	0	1	1	0
Connection to other subjects	1	1	0	1	1	0	1	1	0
Application to the real world	1	1	0	1	1	0	1	1	0
Use of abstractions	1	1	0	1	1	0	1	1	0
Classro	om	cultu	ire q	uest	ions				
Active participation of students encouraged	4	4	0	4	5	1	6	4	2
Teacher's respect for students' ideas	4	4	0	3	4	1	4	4	0
Students' respect for other students' ideas	4	4	0	4	4	0	4	4	0
Students encouraged to generate ideas	2	1	1	3	4	1	3	3	0
Teacher-student collaborative relationships	4	2	2	3	4	1	4	4	0
Student-student collaborative relationships	1	2	1	2	3	1	2	2	0
(	Overall ratings								
Overall implementation rating	3	3	0	4	4	0	3	3	0
Overall content rating	3	3	0	3	3	0	3	3	0
Overall culture rating	3	3	0	3	4	1	4	4	0
Overall summary rating	3	3	0	3	4	1	4	3	1

# Co-Observation Ratings for the Geography 1050b Laboratory Section

	7-Mar-05			14	-Mar-	-05	30	-05	
Classroom observer	1	2	d	1	2	d	1	2	d
Implementat	ion c	of th	e les	son	que	stion	IS		
Instructor confidence	5	5	0	5	5	0	5	5	0
Teacher-student interaction	4	5	1	5	6	1	5	5	0
Classroom management	6	5	1	5	6	1	5	5	0
Pace of the lesson	6	6	0	6	6	0	6	6	0
Student-student interaction	6	6	0	5	6	1	5	5	0
Reflection on the lesson	5	5	0	5	5	0	5	5	0
Wrap-up of the lesson	4	4	0	4	4	0	4	4	0
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	6	6	0	5	6	1	5	5	0
Portrayal of subject matter	5	6	1	5	5	0	4	5	1
Instructor conpetance	7	7	0	7	7	0	7	7	0
Connection to other lessons	4	4	0	3	3	0	4	4	0
Connection to other subjects	1	1	0	1	1	0	1	1	0
Application to the real world	3	4	1	3	3	0	3	3	0
Use of abstractions	6	6	0	6	6	0	6	6	0
Classro	om	cultu	ire q	uest	ions				
Active participation of students encouraged	6	6	0	6	6	0	6	5	1
Teacher's respect for students' ideas	5	6	1	5	6	1	5	5	0
Students' respect for other students' ideas	5	5	0	5	5	0	5	5	0
Students encouraged to generate ideas	5	5	0	6	6	0	5	5	0
Teacher-student collaborative relationships	6	6	0	6	6	0	5	5	0
Student-student collaborative relationships	5	6	1	5	6	1	5	5	0
(	Over	all r	ating	gs					
Overall implementation rating	5	5	0	5	5	0	5	5	0
Overall content rating	5	5	0	5	5	0	5	5	0
Overall culture rating	5	6	1	6	6	0	5	5	0
Overall summary rating	5	5	0	5	5	0	5	5	0

# Co-Observation Ratings for the Geography 1900b Class Section

	7	-Mar-(	05	14-Mar-05			11-Apr-05		
Classroom observer	1	2	d	1	2	d	1	2	d
Implementat	ion c	of the	e les	son	que	stion	IS		
Instructor confidence	5	5	0	5	5	0	5	5	0
Teacher-student interaction	3	4	1	3	3	0	2	3	1
Classroom management	5	4	1	4	4	0	4	4	0
Pace of the lesson	4	4	0	4	4	0	4	4	0
Student-student interaction	6	5	1	5	5	0	5	5	0
Reflection on the lesson	5	6	1	4	3	1	3	4	1
Wrap-up of the lesson	6	6	0	1	1	0	5	5	0
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	6	4	2	5	5	0	4	5	1
Portrayal of subject matter	2	3	1	3	3	0	4	4	0
Instructor conpetance	7	7	0	7	7	0	7	7	0
Connection to other lessons	2	2	0	3	3	0	4	5	1
Connection to other subjects	1	1	0	1	1	0	1	1	0
Application to the real world	2	2	0	2	2	0	2	2	0
Use of abstractions	5	5	0	5	5	0	5	5	0
Classro	om	cultu	ire q	uest	ions				
Active participation of students encouraged	7	6	1	6	6	0	4	5	1
Teacher's respect for students' ideas	4	4	0	4	4	0	3	4	1
Students' respect for other students' ideas	5	6	1	6	6	0	6	6	0
Students encouraged to generate ideas	4	4	0	4	4	0	3	4	1
Teacher-student collaborative relationships	6	6	0	6	5	1	5	5	0
Student-student collaborative relationships	5	6	1	5	5	0	4	5	1
(	Over	all r	ating	gs					
Overall implementation rating	5	5	0	4	4	0	4	4	0
Overall content rating	4	4	0	4	4	0	4	5	1
Overall culture rating	5	5	0	5	5	0	4	5	1
Overall summary rating	5	5	0	4	4	0	4	5	1

# Co-Observation Ratings for the Geography 1900d Class Section

	20	5-Jan-	05	3	l-Jan-	05	7	)5	
Classroom observer	1	2	d	1	2	d	1	2	d
Implementat	ion c	of th	e les	son	que	stion	IS		
Instructor confidence	7	7	0	7	7	0	7	7	0
Teacher-student interaction	6	6	0	6	6	0	6	6	0
Classroom management	6	6	0	5	5	0	6	6	0
Pace of the lesson	4	4	0	4	4	0	4	4	0
Student-student interaction	6	6	0	5	5	0	6	6	0
Reflection on the lesson	6	6	0	6	5	1	6	6	0
Wrap-up of the lesson	7	7	0	4	4	0	5	5	0
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	6	6	0	6	6	0	6	6	0
Portraval of subject matter	6	6	0	6	6	0	6	6	0
Instructor conpetance	7	7	0	7	7	0	7	7	0
Connection to other lessons	4	4	0	3	3	0	3	2	1
Connection to other subjects	4	1	3	1	1	0	1	1	0
Application to the real world	3	3	0	2	1	1	2	2	0
Use of abstractions	3	3	0	3	3	0	3	3	0
Classro	om	cultu	ire q	uest	ions				
Active participation of students encouraged	6	6	0	6	6	0	7	6	1
Teacher's respect for students' ideas	6	6	0	6	6	0	6	6	0
Students' respect for other students' ideas	7	7	0	7	7	0	7	7	0
Students encouraged to generate ideas	6	6	0	6	6	0	6	6	0
Teacher-student collaborative relationships	6	6	0	6	6	0	6	6	0
Student-student collaborative relationships	6	6	0	5	5	0	6	6	0
(	Dver	all r	ating	gs					
Overall implementation rating	6	6	0	5	5	0	6	6	0
Overall content rating	5	5	0	4	4	0	4	4	0
Overall culture rating	6	6	0	6	6	0	6	6	0
Overall summary rating	6	6	0	5	5	0	6	5	1

# Co-Observation Ratings for the Geosciences 2900 Class Section

Appendix L

A Comparison of the SAMPI Lesson Observation System Ratings Assigned by the Primary Researcher and by the Co-Rater

	2	l-Jan-	05	21	l-Jan-	05	21-Feb-05		
Classroom observer	1	1	LdT	2	2	141	1	1	LdT
Observation coder	а	b	Tai	а	b	Tai	а	b	Tai
Implementation of the lesson questions									
Instructor confidence	6	5	1	6	6	0	6	6	0
Teacher-student interaction	2	2	0	3	4	1	5	5	0
Classroom management	2	3	1	3	3	0	5	4	1
Pace of the lesson	4	4	0	4	4	0	4	5	1
Student-student interaction	1	1	0	1	1	0	1	1	0
Reflection on the lesson	1	1	0	1	3	2	4	5	1
Wrap-up of the lesson	1	1	0	1	2	1	3	3	0
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	2	2	0	3	2	1	5	4	1
Portrayal of subject matter	1	2	1	1	2	1	1	4	3
Instructor conpetance	7	7	0	7	7	0	7	7	0
Connection to other lessons	2	3	1	2	3	1	2	4	2
Connection to other subjects	2	2	0	2	2	0	2	3	1
Application to the real world	2	2	0	2	2	0	2	2	0
Use of abstractions	6	6	0	5	6	1	2	2	0
Classro	om o	cultu	ire q	uest	ions	1			
Active participation of students encouraged	2	4	2	4	4	0	5	5	0
Teacher's respect for students' ideas	2	4	2	4	4	0	5	5	0
Students' respect for other students' ideas	1	1	0	1	1	0	4	5	1
Students encouraged to generate ideas	3	3	0	3	3	0	5	5	0
Teacher-student collaborative relationships	1	1	0	1	1	0	1	1	0
Student-student collaborative relationships	2	3	1	3	3	0	5	3	2
(	Dver	all r	ating	gs					
Overall implementation rating	2	3	1	3	4	1	4	5	1
Overall content rating	4	3	1	4	3	1	4	5	1
Overall culture rating	2	3	1	3	3	0	4	5	1
Overall summary rating	3	3	0	3	3	0	4	5	1

# Co-Ratings for the Geography 1050b Lecture Section

	19	9-Jan-	05	2	-Feb-(	05	2-Feb-05		
Classroom observer	1	1	1.4.1	1	1	1.4.1	2	2	1.4.1
Observation coder	а	b	101	а	b	Idi	а	b	Idi
Implementati	ion o	of th	e les	son	que	stion	IS		
Instructor confidence	5	4	1	5	5	0	5	5	0
Teacher-student interaction	3	3	0	3	3	0	2	2	0
Classroom management	4	4	0	4	4	0	3	4	1
Pace of the lesson	4	4	0	4	4	0	4	4	0
Student-student interaction	4	5	1	4	5	1	3	4	1
Reflection on the lesson	3	2	1	3	2	1	3	2	1
Wrap-up of the lesson	1	2	1	1	2	1	1	2	1
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	4	3	1	4	3	1	2	3	1
Portrayal of subject matter	4	3	1	4	3	1	4	3	1
Instructor conpetance	5	6	1	6	6	0	5	6	1
Connection to other lessons	1	2	1	1	2	1	1	1	0
Connection to other subjects	1	1	0	1	1	0	1	1	0
Application to the real world	1	1	0	1	1	0	1	1	0
Use of abstractions	1	1	0	1	1	0	1	1	0
Classro	om	cultu	ire q	uest	ions	5			
Active participation of students encouraged	4	4	0	6	4	2	4	4	0
Teacher's respect for students' ideas	4	4	0	4	3	1	4	3	1
Students' respect for other students' ideas	4	5	1	4	3	1	4	3	1
Students encouraged to generate ideas	2	2	0	3	2	1	3	2	1
Teacher-student collaborative relationships	4	5	1	4	3	1	4	4	0
Student-student collaborative relationships	1	2	1	2	2	0	2	2	0
(	Dver	all r	ating	gs					
Overall implementation rating	3	3	0	3	4	1	3	3	0
Overall content rating	3	4	1	3	3	0	3	3	0
Overall culture rating	3	3	0	4	3	1	4	3	1
Overall summary rating	3	3	0	4	3	1	3	3	0

# Co-Ratings for the Geography 1050b Laboratory Section

Co-Ratings for the Geography 1900b Class Section	
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	14-Mar-05			14-Mar-05			23-Mar-05		
Classroom observer	1	1	LAL	2	2	141	1	1	141
Observation coder	а	b	101	а	b	Idi	а	b	101
Implementation of the lesson questions									
Instructor confidence	5	5	0	5	5	0	5	6	1
Teacher-student interaction	5	5	0	6	5	1	5	5	0
Classroom management	5	5	0	6	5	1	7	6	1
Pace of the lesson	6	6	0	6	6	0	6	6	0
Student-student interaction	5	5	0	6	5	1	5	5	0
Reflection on the lesson	5	4	1	5	4	1	5	5	0
Wrap-up of the lesson	4	4	0	4	4	0	4	5	1
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	5	6	1	6	6	0	6	6	0
Portrayal of subject matter	5	6	1	5	6	1	5	6	1
Instructor conpetance	7	7	0	7	7	0	7	7	0
Connection to other lessons	3	3	0	3	3	0	4	2	2
Connection to other subjects	1	2	1	1	2	1	1	2	1
Application to the real world	3	2	1	3	4	1	4	2	2
Use of abstractions	6	5	1	6	5	1	6	6	0
Classroom culture questions									
Active participation of students encouraged	6	5	1	6	5	1	7	6	1
Teacher's respect for students' ideas	5	6	1	6	6	0	5	6	1
Students' respect for other students' ideas	5	5	0	5	5	0	5	5	0
Students encouraged to generate ideas	6	5	1	6	5	1	5	5	0
Teacher-student collaborative relationships	6	6	0	6	6	0	7	6	1
Student-student collaborative relationships	5	5	0	6	5	1	5	6	1
Overall ratings									
Overall implementation rating	5	5	0	5	5	0	5	5	0
Overall content rating	5	5	0	5	5	0	5	5	0
Overall culture rating	6	5	1	6	5	1	6	6	0
Overall summary rating	5	5	0	5	5	0	5	5	0

<b>Co-Ratings</b>	for the	Geography	1900d	<b>Class Section</b>
0				

	11-Apr-05			11-Apr-05			9-Mar-05		
Classroom observer	1	1	141	2	2	141	1	1	141
Observation coder	а	b	Tur	а	b	Tur	а	b	Tur
Implementation of the lesson questions									
Instructor confidence	5	5	0	5	5	0	5	5	0
Teacher-student interaction	2	2	0	3	3	0	4	2	2
Classroom management	4	4	0	4	4	0	6	4	2
Pace of the lesson	4	5	1	4	5	1	4	5	1
Student-student interaction	5	5	0	5	5	0	6	5	1
Reflection on the lesson	3	4	1	4	4	0	5	3	2
Wrap-up of the lesson	5	4	1	5	4	1	1	3	2
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	4	5	1	5	5	0	6	4	2
Portrayal of subject matter	4	3	1	4	3	1	4	4	0
Instructor conpetance	7	7	0	7	7	0	7	7	0
Connection to other lessons	4	5	1	5	4	1	3	2	1
Connection to other subjects	1	2	1	1	2	1	1	2	1
Application to the real world	2	2	0	2	2	0	3	2	1
Use of abstractions	5	5	0	5	4	1	5	3	2
Classroom culture questions									
Active participation of students encouraged	4	4	0	5	4	1	6	4	2
Teacher's respect for students' ideas	3	3	0	4	4	0	4	4	0
Students' respect for other students' ideas	6	5	1	6	5	1	6	5	1
Students encouraged to generate ideas	3	4	1	4	4	0	6	3	3
Teacher-student collaborative relationships	5	6	1	5	6	1	6	6	0
Student-student collaborative relationships	4	4	0	5	5	0	6	4	2
Overall ratings									
Overall implementation rating	4	4	0	4	4	0	4	4	0
Overall content rating	4	5	1	5	5	0	5	4	1
Overall culture rating	4	4	0	5	4	1	6	4	2
Overall summary rating	4	4	0	5	4	1	5	4	1
# Table L.5

	19-Jan-05			7-Feb-05			7-Feb-05		
Classroom observer	1	1	LAL	2	2	141	1	1	141
Observation coder	а	b	Tai	а	b	Tai	а	b	Tai
Implementation of the lesson questions									
Instructor confidence	7	6	1	7	7	0	7	7	0
Teacher-student interaction	4	5	1	6	7	1	6	6	0
Classroom management	5	6	1	6	6	0	6	6	0
Pace of the lesson	4	5	1	4	6	2	4	6	2
Student-student interaction	5	6	1	6	6	0	6	6	0
Reflection on the lesson	4	5	1	6	6	0	6	5	1
Wrap-up of the lesson	1	3	2	5	4	1	5	4	1
Content of the lesson questions									
Importance of the content	7	7	0	7	7	0	7	7	0
Intellectual engagement of students	5	5	0	6	6	0	6	6	0
Portrayal of subject matter	6	5	1	6	6	0	6	6	0
Instructor conpetance	7	6	1	7	7	0	7	7	0
Connection to other lessons	2	2	0	2	2	0	3	2	1
Connection to other subjects	1	1	0	1	1	0	1	1	0
Application to the real world	3	2	1	2	1	1	2	2	0
Use of abstractions	3	2	1	3	1	2	3	3	0
Classroom culture questions									
Active participation of students encouraged	5	5	0	6	6	0	7	6	1
Teacher's respect for students' ideas	5	5	0	6	6	0	6	6	0
Students' respect for other students' ideas	7	5	2	7	6	1	7	6	1
Students encouraged to generate ideas	4	5	1	6	6	0	6	5	1
Teacher-student collaborative relationships	5	6	1	6	6	0	6	6	0
Student-student collaborative relationships	4	5	1	6	6	0	6	6	0
Overall ratings									
Overall implementation rating	4	5	1	6	6	0	6	6	0
Overall content rating	4	5	1	4	5	1	4	5	1
Overall culture rating	5	5	0	6	6	0	6	6	0
Overall summary rating	5	5	0	5	6	1	6	6	0

# Co-Ratings for the Geosciences 2900 Class Section

Appendix M

Interview Findings

#### Benchmark E.2

#### Geography 1050

The drawings constructed by the three Geography 1050a section interviewees (S-59, S-90, and S-139) and by the seven Geography 1050b section interviewees (S-5, S-10, S-56, S-76, S-98, S-104, and S-122) are in Figure M.1.

Two of the three Geography 1050a section interviewees (S-59 and S-139) and four of the seven Geography 1050b section interviewees (S-5, S-56, S-98, and S-122) were able to adequately explain that the tilt of the earth is the primary reason for why it is colder in Michigan during December and January than during June and July, although only S-59 stated that the angle of the tilt is 23.5°. S-139 did not know the exact angle of the tilt, but suggested that it was something like 21.5° or 25°. S-122 was able to illustrate that the Northern Hemisphere is tilted toward the sun during winter, but incorrectly showed the circle of illumination coinciding with the tilt (Figure M.1i).

The remaining Geography 1050a section interview (S-90) and the three remaining Geography 1050b section interviewees (S-10, S-76, and S-104) were unable to adequately explain why it is colder in Michigan during the winter months.

S-90 stated that a polar air mass would be cool even during July because "up north the seasons vary more and it's farther away from the equator." When asked how being further from the equator could explain the colder temperatures, S-90 stated, "Because it tilts more, and closer to the equator there is less variation in seasons... In the winter, it's tilted away, and it gets a lot less sun light, so it's colder." However, this interviewee could not explain what was meant by the phrase "tilted away." The drawing shows *the equator* tilted at an angle (Figure M.1f); thus, there is no evidence that the interviewee understood that *the earth itself* is tilted. This drawing also incorrectly shows the Southern Hemisphere facing the sun in July. This was verbally corrected later, however, when the interviewee stated that the Northern Hemisphere should be facing the



Figure M.1. Illustrations for Why it is Colder in Michigan during December than during June (Geography 1050 Interviewees).

sun in July. S-90 was also unable to explain to what extent "less sun light" relates to the sun angle and the length of daylight.

S-10 correctly stated that it is colder in December and January in Michigan "because of our position on the earth, and the earth's axis, and tilt, and rotation." However, S-10 was unable to explain these terms, and initially drew the northern hemisphere tilted toward the sun during both winter and summer (Figure M.1b). When asked to clarify when the Northern Hemisphere is tilted toward the sun, S-10 became silent and made no response. The interviewee then modified the drawing to produce the final form that appears in Figure M.1b. When asked why the drawing was modified, S-10 responded, "Uh…because you questioned it, I guess."

The drawing constructed by S-76 illustrates when the various seasons begin, but does not show the earth's tilt, nor where the sun's direct rays are located during the significant months (Figure 7e). Nonetheless, when asked why it is colder in Michigan in December than in June, S-76 responded, "Because we're...facing the sun more when it's in June than December, so...the sun is shining more toward North America in June than December." No comprehension, however, was expressed that "we're facing the sun" because the earth is tilted. When asked when the highest sun angle occurs in Michigan, S-76 responded, "I can't remember." After receiving hints from the interviewer, S-76 finally stated that the highest sun angle occurs at noon. However, no statements were made about *what time of year* the highest sun angle occurs.

S-104 stated that it is darker in the Northern Hemisphere "far longer in winter" because of the tilt, rotation, parallelism of the axis, and revolution of the earth. However, none of these terms were explained. They appear to have merely been memorized items from a list. S-104 was able to illustrate the tilt of the earth for the date of December 21 (Figure M.1h), but the equator was poorly placed.

One of the three Geography 1050a section interviewees (S-59) and two of the seven Geography 1050b section interviewees (S-76 and S-98) stated that Michigan

experiences its lowest sun angle during the winter and/or its highest sun angle during the summer. S-59 stated that Michigan is getting the least amount of direct radiation from the sun on December 21. S-76 stated that the sun angle in Michigan is high in June. S-98 stated that "the earth isn't warmed as much in the Northern Hemisphere" during December "because of the declination of the sun. It...the sun's light isn't as direct, so the same amount of light is spread over a larger area, so it's not warm." Significant misconceptions were expressed by S-122, who incorrectly stated that the highest sun angle in Michigan occurs "a little bit after the summer solstice," and that the lowest sun angle occurs in Michigan during January even though the winter solstice occurs in December. When asked to explain why the lowest sun angle does not coincide with the winter solstice, S-122 responded, "I don't know."

Two of the three Geography 1050a section interviewees (S-59 and S-139) and four of the seven Geography 1050b section interviewees (S-10, S-56, S-98, and S-122) made statements about the location of the sun's direct rays. S-10 stated that the summer solstice occurs on June 22. S-56 stated that the sun's rays are "gonna' be…perpendicular at the Northern Hemisphere" in June, and over the Southern Hemisphere during the winter. S-56 also stated that the "sub-solar" point" is at 23.5° N on June 21, and that "the sun's rays are going at the bottom…the Southern Hemisphere." S-59 stated that the sun's direct rays are located at the Tropic of Cancer on June 21, the Tropic of Capricorn on December 21, and the equator on both of the equinoxes. S-98 stated that the sun's light is "more concentrated" on December 21 "right on the Tropic of Capricorn." S-122 stated that the sunlight is "hitting directly on the equator in spring and fall," and that "it's not hitting directly on the equator" in June. However, this interviewee incorrectly stated that the sunlight is hitting directly at 30° N in June. S-139 stated that the Northern Hemisphere is getting more energy during July. However, this interviewee incorrectly thought that the sun's direct rays were concentrated at 35° S during the winter.

Three of the seven Geography 1050b section interviewees (S-5, S-104, and S-122) stated that the days in Michigan are longer during the summer and shorter during the winter. No statements about this were made by the Geography 1050a section interviewees. S-5 stated that the longest day in Michigan occurs on June 21. S-104 stated that it is darker in the Northern Hemisphere "far longer in winter." S-122 incorrectly stated that the shortest day occurs during January even though the winter solstice occurs in December. When asked to explain why the shortest day does not coincide with the winter solstice, S-122 responded, "I don't know."

One of the seven Geography 1050b section interviewees (S-98) stated that the sunset time in Michigan gets later as the calendar moves from December to June. No statements about this were made by the Geography 1050a section interviewees.

None of the interviewees stated that the earth rotates on its axis.

One of the three Geography 1050a section interviewees (S-139) directly stated that the earth's orbit around the sun is elliptical. However, the drawing constructed by another Geography 1050a section interviewee (S-59) demonstrated knowledge that the earth's orbit around the sun is elliptical. No knowledge about this was expressed by the Geography 1050b section interviewees.

## Geography 1900

The drawings constructed by the three Geography 1900a section interviewees (S-9, S-85, and S-91) and by the four Geography 1900b section interviewees (S-95, S-103, S-114, and S-169) are in Figure M.2. The drawings constructed by the three Geography 1900c section interviewees (S-41, S-71, and S-89) and by the Geography 1900d section interviewee (S-83) are in Figure M.3.

One of the three Geography 1900a section interviewees (S-85) and two of the four Geography 1900b section interviewees (S-95 and S-103) and the Geography 1900d section interviewee (S-83) were able to adequately explain that the tilt of the earth is the



Figure M.2. Illustrations for Why it is Colder in Michigan during December than during June (Geography 1900a and Geography 1900b Interviewees).



Figure M.3. Illustrations for Why it is Colder in Michigan during December than during June (Geography 1900c and Geography 1900d Interviewees).

primary reason for why it is colder in Michigan during December and January than during June and July, although S-85 portrayed the position of the equator incorrectly (Figure M.2b). One Geography 1900a section interviewee (S-9) and one Geography 1900b section interviewee (S-114) did not make verbal statements about the tilt, but knowledge was implied by their drawings (Figures M.2a and M.2f). None of the interviewees stated that the angle of the tilt is 23.5°, although S-103 estimated that it was "about a 30 something degree angle."

The remaining Geography 1900a section interview (S-91), the remaining Geography 1900b section interviewees (S-169), and all three of the Geography 1900c section interviewees (S-41, S-71, and S-89) were unable to adequately explain or illustrate why it is colder in Michigan during the winter months.

S-41 stated that "the tilt of the earth makes the Northern Hemisphere away from the sun," but was unable to explain what this meant. The drawing constructed by S-41 illustrates the Southern Hemisphere facing the sun during December, but portrays the equator as if it was the earth's tilt (Figure M.3a).

S-71 appeared to express comprehension by stating that it is colder in Michigan during December because of "the way that the earth is tilted toward the sun." This interviewee even accurately illustrated it through a drawing (Figure M.3b). However, other comments by this interviewee suggest that S-71 didn't truly comprehend the concepts that were being expressed. The interviewee stated that "the Southern Hemisphere is closer to the sun" when it is tilted toward the sun, "so they get, like, closer rays. It doesn't take the sun as long...as far."

S-89 initially drew the Southern Hemisphere facing the sun in December and the Northern Hemisphere facing the sun in June, but gave no indication of the tilt (Figure M.3d). When it was pointed out that the drawing appears to show the sun's rays hitting the South Pole in December, S-89 constructed a smaller earth with a slanted equator. The interviewee was unable to explain the new diagram and stated, "I don't know that exact

tilt. I can't draw." S-89 was then asked to state what latitude the sun's direct rays are "hitting" in December, but was unable to do so:

- Bob: Okay. And the latitude, um...can... The sun's direct rays: what hemisphere would they be hitting?
- S-89: The southern.
- Bob: The Southern Hemisphere. Do you have a general idea of how far north or south...?
- S-89: How far north it's reaching?
- Bob: Where the sun's direct rays are. Like, if you were to look straight overhead at noon on that date, you would see the sun. Where would that be?
- S-89: Like...like this picture right here. Like, if [the pole] is 90, and then it's gonna' be probably here...um... Thirty? (*The student adds "30" to the small drawing of the earth, as well as an unreadable mark to indicate the South Pole.*) Is that what you're asking?

S-91 listed several reasons why it is colder in December: the tilt of the earth,

direction of sunlight, reflection, and number of daylight hours. However, S-91 did not adequately explain these concepts. In fact, the initial explanation is extremely confusing: "Well...tilted...um...more so that the southern hemisphere is in more direct comparison to the sun than the northern hemisphere...the sun is more direct in direct to the southern hemisphere in...in January and December than in..." This interviewee also had a great deal of difficulty explaining the drawing that was constructed (Figure M.2c). When asked where in the drawing the equator is, the interviewee became silent and gave no response. When asked which of the four outer circles in the drawing represents winter in Michigan, S-91 pointed to the top circle, but then suddenly pointed to the circle on the left and stated, "No! January is supposed to be right here...isn't it?" S-91 then recalled that a more detailed diagram was constructed in class, but was unable to draw it. The interviewee became quite flustered, and was allowed to start over. However, the explanation that followed was unclear and difficult to follow:

The sun is here, right? (*The interviewee points to circle in the center of the diagram.*) I'm better at objects! And you got your planet going around it, and in the summertime the earth is shifted so that the northern

hemisphere, our area, is in, like, direct comparison to the sun. As the sun goes around, it tilts, like, more and then we have our next season where we're having the most daylight shifting hours as far as...um, or more daylight shifting hours, like, in the winter it's, like...in the winter it equals out as far as negative/positive, as far as daylight hours, than in the summer. And it gets, because of the tilt of the earth and daylight hours...it gets farther away from the sun in the fall. And then in the winter, it's the farthest away from the sun... No, wait! Not "away from the sun!" Like, the tilt of the earth is!

S-169 stated that seasons exist because of "the rotation of the earth around the sun, and the direct sunlight." This interviewee was unable to explain these terms, however, except to say that it is "probably" winter when "there's more sunlight in the south." When asked when the longest day occurs in the Southern Hemisphere, S-169 responded, "The equinox?" When asked what "equinox means, the interviewee stated, "That they have the same amount of daylight" at all places in the world. When asked if that is what is experienced when the Southern Hemisphere has its longest day, the interviewee changed and said, "No." S-169 then suggested that the longest day in the Southern Hemisphere occurs in June because "it's June in the south and December in the north" when Michigan has its shortest days. When the interviewee was told that it is December everywhere in the world at the same time, S-169 drew a small earth to the lower right of the sun (Figure M.2g). However, when S-169 was asked to explain this addition to the drawing, the interviewee declared, "I don't know. Ha ha."

One of the three Geography 1900a section interviewees (S-85), two of the four Geography 1900b section interviewees (S-95 and S-114), and one of the three Geography 1900c section interviewees (S-71) stated that Michigan experiences its lowest sun angle during the winter and/or its highest sun angle during the summer. S-71 correctly stated that it is colder in Michigan during winter "because there's indirect rays coming, and the more direct rays are down…in the Southern Hemisphere." However, S-71 incorrectly thought that "indirect" rays occur in the hemisphere that is "farther away" from the sun. S-85 stated that seasons in Michigan are caused "not really [by] how far we are away

from the sun, but the daylight hours that we get, and the angle at which we get our sun... But mostly...you get a more head-on angle, you're gonna' get more sunlight, and then...more heat because of that." S-95 stated that Michigan experiences its highest sun angle on June 21. S-114 stated that it is colder in Michigan during winter because there is "just not a 'dead on' angle of sunlight" at that time.

All three Geography 1900a section interviewees (S-9, S-85, and S-91), three of the four Geography 1900b section interviewees (S-95, S-103, and S-114), and two of the three Geography 1900c section interviewees (S-71 and S-89) made statements about the location of the sun's direct rays. S-9 stated that the sun's direct rays are "below the equator" during December and "in the Northern Hemisphere" during July. S-71 stated that the sun's direct rays are located at the equator on March 21 and September 21. However, S-71 incorrectly placed the sun's direct rays at the latitudes of 30° N and 30° S during the solstices. S-85 stated that the south is now facing the sun, and the north does not have direct rays." S-91 stated that the sun's direct rays are "more in the southern hemisphere" when Michigan is experiencing winter. S-103 stated that the winter solstice occurs on December 21. S-114 stated that the sun's direct rays are "hitting...certain areas," and that the sun angle is "less" at areas further from where the sun's direct rays are "hitting." S-9, S-95, and S-114 illustrated through their drawings that the sun's direct rays are sys are concentrated at particular latitudes (Figures M.2a, M.2d, and M.2f).

One of the three Geography 1900a section interviewees (S-85), two of the four Geography 1900b section interviewees (S-103 and S-114), and the Geography 1900d section interviewee (S-83) stated that the days in Michigan are longer during the summer and shorter during the winter. S-83 stated that the longest day of the year in Michigan occurs in June. S-85 and S-103 stated that December 21 is the shortest day of the year. S-41 incorrectly stated that the longest day occurs on March 21. When the interviewee was asked to explain how the length of daylight was changing at the time of the interview

(April 15, 2005), the interviewee realized that the days had been getting longer, and changed to say that September 21 is the longest day and March 21 is the shortest day.

None of the interviewees stated that the sunset time in Michigan gets later as the calendar moves from December to June.

None of the interviewees directly stated that the earth's orbit around the sun is elliptical, but one of the Geography 1900b section interviewees (S-95) implied this knowledge through a drawing (Figure M.2d).

One of the three Geography 1900b section interviewees (S-103) stated that the earth rotates on its axis. In fact, S-103 illustrated the earth spinning about its axis (Figure M.2e).

#### Geosciences 2900

The drawings constructed by the three Geosciences 2900 section interviewees (S-78, S-79, and S-117) are in Figure M.4.

One of the three Geosciences 2900 section interviewees (S-117) adequately explained that the tilt of the earth is the primary reason for why it is colder in Michigan during December and January than during June and July. None of the interviewees stated that the angle of the tilt is 23.5°.

Two Geosciences 2900 section interviewees (S-78 and S-79) were unable to explain why it is colder in Michigan during the winter months.

S-78 understood that it is colder in Michigan during the winter "because we're not facing the sun." This interviewee, however, constructed the poorest drawing of any of the interviewees (Figure M.4a). The drawing illustrates the Southern Hemisphere "facing the sun" and the Northern Hemisphere "facing away from the sun." However, the interviewee stated that the diagonal line represents the equator. Therefore, no knowledge was expressed that the earth is tilted on its axis. It is unclear what the circle in the lower right portion of the diagram was meant to show. When asked what it was, the



Figure M.4. Illustrations for Why it is Colder in Michigan during December than during June (Geosciences 2900 Interviewees).

interviewee simply responded, "I don't know."

S-79 adequately illustrated the tilt in a drawing (Figure M.4b) and even stated that it is colder in winter "because we're tilted during the winter; we're not receiving as much direct sunlight." However, this interview gave a poor explanation when probed about it. It was stated that the sun's direct rays are at the equator on December 21, March 21, June 21, and September 21. When asked if the sun's direct rays ever move, S-79 responded, "Well, the equator receives the most direct sunlight." When asked how the sun angle changes in Michigan if the sun's angle is always directly overhead at the equator, S-79 responded that the sun angle is "gonna' shift slightly," but could not explain how or why. When asked how "slightly" the sun angle will shift, the interviewee ignored the question and changed to say that the location of the sun's direct rays will shift from "zero to thirty degrees." When asked to explain the significance of thirty degrees, the interviewee said, "Well, that's where the ITCZ is."

All three of the Geosciences 2900 section interviewees stated that Michigan experiences its lowest sun angle during the winter and/or its highest sun angle during the summer. S-78 stated that Michigan experiences its highest sun angle on June 21. S-79 adequately illustrated the angle at which the sun strikes the earth (Figure M.4b), and stated that the sun angle in Michigan has "gotta' be lower" in December," but that it is "closer to 90° [in June], but I don't think [it's] ever gonna' be completely at 90 because [it's] still angled no matter what the case is." S-117 stated that the highest sun angle in Michigan is "maybe like 70" degrees. This interviewee also adequately illustrated the difference between direct and indirect incoming solar rays (Figure M.4c), stated that the sun angle is based on the distance between the latitude at which Michigan is found and the latitude at which the sun's direct rays are found, and stated that the sun angle in Michigan is never directly overhead.

All three Geosciences 2900 section interviewees made statements about the location of the sun's direct rays, but two of them (S-79, and S-117) expressed significant misconceptions. S-78, the only Geosciences 2900 section interviewee who did not express misconceptions about the location of the sun's direct rays, stated that the summer solstice occurs in June. S-79 stated that the sun's direct rays are at the equator on March 21 and September 21, but incorrectly stated that the sun's direct rays are at the equator on December 21 and June 21. S-117 initially stated that the sun's direct rays are "somewhere in the Northern Hemisphere" in June. However, this interviewee changed to say that the sun's direct rays are at the equator during January and June, and over the Northern Hemisphere during March "because it's leading into our summer." This was inconsistent with the interviewee's statement that the highest sun angle in Michigan "probably" occurs during the summer.

None of the Geosciences 2900 section interviewees stated that the longest and shortest days in Michigan occur on June 21 and December 21 respectively, that the sunset time gets later as the calendar moves from December to June, or that the earth rotates on its axis.

None of the Geosciences 2900 section interviewees stated that the earth's orbit around the sun is elliptical. S-117 stated that "the earth is always the same distance from the sun. That doesn't change. It's a circle."

#### Benchmark E.3

#### Geography 1050

*Question 1: What is the difference between a severe weather "watch" and a severe weather "warning?"* One of the three Geography 1050a section interviewees (S-59) and all seven of the Geography 1050b section interviewees (S-5, S-10, S-56, S-76, S-98, S-104, and S-122) were asked to differentiate between a severe weather "watch" and

a severe weather "warning." Half of them (S-59, S-76, S-98, and S-122) were adequately able to do so. The best definitions was given by S-122, who said that a "watch" means that one should be on the look-out because "conditions are favorable for severe storms or a tornado," and a "warning" means that "a tornado has been sighted and you should seek shelter, or...that severe storms are...approaching, and we should seek shelter." Two Geography 1050a section interviewees (S-90 and S-139) were not asked to differentiate between a "watch" and a "warning."

Two of the Geography 1050b section interviewees (S-5 and S-56) did not know the precise difference between a "watch" and a "warning," but stated that a "warning" should be taken more seriously than a "watch." S-56 stated that one should "go into the basement" during a "warning."

Two of the Geography 1050b section interviewees (S-10 and S-104) possessed a significant lack of knowledge about "watches" and "warnings." S-10 stated that a "warning" is "when they're predicting it to happen," and a "watch" is "when they see one." S-104 admitted having no idea what the difference is. When the researcher suggested that this might be a problem because "you don't know whether to seek shelter or not," the interviewee laughed and said, "Right! Maybe you should tell me after this!"

Question 2: What is the difference between a thunderstorm that is "severe" and one that is not? All three Geography 1050a section interviewees (S-59, S-90, and S-139) and three of the seven Geography 1050b section interviewees (S-5, S-56, and S-98) were asked to differentiate between a thunderstorm that is "severe" and one that is not. One of the Geography 1050a section interviewees (S-59) stated that a "severe" storm is categorized only by large hail and/or strong winds. This interviewee recognized that a "severe" thunderstorm has wind speeds stronger than a certain "designation" and hail bigger than a certain "diameter." S-59 also stated that a "severe" storm has precipitation and "usually lightning," but it did not appear that this interviewee was suggesting that precipitation and lightning are included in the criteria for classifying a storm as "severe."

Four Geography 1050b section interviewees (S-10, S-76, S-104, and S-122) were not asked to differentiate between a thunderstorm that is "severe" and one that is not.

Partial knowledge was observed for one Geography 1050a section interviewee (S-90) and one Geography 1050b section interviewee (S-98). S-90 recognized that a "severe" storm can have "high winds." S-98 stated that a "severe" storm usually has "the anvil-shaped cumulonimbus clouds," and that "a lot of times there's an updraft that can cause hail, and stuff." When asked if it was possible to have such a storm that is not "severe," this interviewee stated, "Yeah. It's just not as big."

Two of the three Geography 1050a section interviewees (S-90 and S-139) and two of the three Geography 1050b section interviewees who were asked this question (S-5 and S-56) incorrectly thought that lightning has something to do with a storm being classified as "severe." S-5 stated that a "severe" thunderstorm "has more lightning and thunder," and that the lightning in the storm "actually touches the ground more and causes more damage." S-56 said that a "severe" storm is one that is "really violent" in terms of thunder and lightning, but a "non-severe" storm "won't have as frequent thunderstorms and lightning." S-90 stated that a "severe" storm has "a lot of lightning and hitting the ground." S-139 thought that "if there's a thunderstorm with lightning, then they'll issue a 'severe thunderstorm warning." This interviewee expressed uncertainty about whether or not there could be a thunderstorm that is *not* classified as "severe."

One Geography 1050b section interviewee (S-5) incorrectly thought that rain has something to do with a storm being classified as "severe." This interviewee stated that a "severe" thunderstorm has "more" rain than a "non-severe" storm. One Geography 1050a section interviewee (S-90) stated that a "severe" storm has "rain and flooding," but it did not appear that this interviewee was suggesting that precipitation and flooding are included in the criteria for classifying a storm as "severe."

*Question 3: What actions should teachers and students take if they are in a school when a tornado is approaching?* One of the three Geography 1050a section interviewees (S-59) and all seven Geography 1050b section interviewees were asked to explain what teachers and students should do when a tornado is approaching a school. Two Geography 1050a section interviewees (S-90 and S-139) were not asked this question.

The Geography 1050a section interviewee (S-59) and four of the seven Geography 1050b section interviewees (S-5, S-10, S-56 and S-104) stated that children should be taken to areas away from the windows. S-56 even said that children should not be kept in the classroom "cause there might be windows."

The Geography 1050a section interviewee (S-59) and six of the seven Geography 1050b section interviewees (S-10, S-56, S-76, S-98, S-104, and S-122) stated that it was important to get to the "center of the building," the "internal walls," the hallways, or the interior of the building. S-5 said to take the children to a small room, like a janitor's closet or a bathroom.

Five of the seven Geography 1050b section interviewees (S-5, S-10, S-98, S-104, and S-122) said that it was important to cover or protect the head and/or neck with hands or books.

Three of the seven Geography 1050b section interviewees (S-104, S-98, and S-122) said that it was important to "crouch" or "kneel." S-5 stated that teachers should have children "all sit down."

The Geography 1050a section interviewee (S-59) said that it was important to not go outside. This interviewee also stated that it was important to "basically...stay away from anything that might fly around and hurt you."

*Question 4: Should the windows be opened when a tornado is approaching?* One Geography 1050a section interviewee (S-59) and all seven Geography 1050b section interviewees stated that the windows should not be opened when a tornado is

approaching, or that opening the windows should not be a primary concern. One Geography 1050b section interviewee (S-98) even joked about it:

S-98: Open all the windows, put lots of sharp objects...

Bob: Oh, you're joking, right?

S-98: Yeah. Ha ha.

Two Geography 1050a section interviewees (S-90 and S-139) were not asked this question.

The Geography 1050a section interviewee (S-59) and four of the seven Geography 1050b section interviewees (S-5, S-10, S-76, and S-122) were asked to explain why the windows should not be opened. Only S-5 and S-122 gave an adequate explanation. S-5 said, "Having the windows shut would keep the wind and air out more...than keeping them open." S-122 said, "So the air couldn't rush in and rip the roof off the building."

Two of the Geography 1050b section interviewees (S-10 and S-76) wrongly thought that the reason for not opening the windows has something to do with the pressure. S-10 said, "There's gonna' be all this air pressure, like, coming in really fast." This interviewee, however, may have confused pressure with wind, because the interviewee went on to say that "all the papers and things will go everywhere." S-76 stated that opening the windows would increase the pressure inside the building, but thought that this was because the force of the wind would increase the pressure.

The Geography 1050a section interviewee (S-59) could not explain why the windows should not be opened. However, this interviewee recognized that the reason has nothing to do with the pressure: "Some people think it equalizes pressure, but...I think it's wrong."

# Geography 1900

*Question 1: What is the difference between a severe weather "watch" and a severe weather "warning?"* One of the three Geography 1900a section interviewees (S-

91), the four of the Geography 1900b section interviewees (S-95, S-103, S-114, and S-169), the three Geography 1900c sections interviewees (S-41, S-71, and S-89) and the Geography 1900d section interviewee (S-83) were asked to differentiate between a severe weather "watch" and a severe weather "warning." The Geography 1900a section interviewee (S-91), one of the Geography 1900b section interviewees (S-103), two of the Geography 1900c section interviewees (S-71 and S-89) and the Geography 1900d section interviewee (S-83) were adequately able to do so. The best explanations were given by S-89 and S-103. S-89 stated that a "watch" means "that things are likely for that to happen and you should take caution. I mean, if you were planning a trip to the beach, you should probably not go. And, uh, a 'warning' means that it has happened." S-103 said that a "watch" means that "the conditions are right for a thunderstorm to take place" and that "you should…keep an eye out for those things," while a "warning" means that "it will come or it has been spotted."

Three of the four Geography 1900b section interviewees (S-95, S-114, and S-169) and one of the three Geography 1900d section interviewees possessed a significant lack of knowledge about "watches" and "warnings." S-41 stated that a "watch" is issued "when the conditions are right for a thunderstorm," but expressed a misconception that a "warning" is issued when a severe thunderstorm has been spotted "in another county that's coming your way." S-95 gave the most superficial response by stating that "the 'watch' is that you're watching for it to come" and "the 'warning' is that you're being warned that it's coming." S-114 wasn't sure what the difference was but suggested that a "warning" meant to be on the look-out because "there are signs on the Doppler Radar that maybe we'll be having problems," and a "watch" means that "they've seen something touch down in the nearby area." S-169 said that a "warning" is issued when "there's one spotted in your county."

*Question 2: What is the difference between a thunderstorm that is "severe" and* one that is not? The three Geography 1900a section interviewees (S-9, S-85 and S-91), the four Geography 1900b section interviewees (S-95, S-103, S-114, and S-169), two of the three Geography 1900c section interviewees (S-41 and S-71), and the Geography 1900d section interviewee (S-83) were asked to differentiate between a thunderstorm that is "severe" and one that is not. Only S-41 recognized that a "severe" thunderstorm is characterized *only* by large hail and/or damaging winds. S-83 stated that "severe" storms are characterized by large hail and strong winds, but did not realize that this is the only criteria used. All interviewees with the exception of S-71 stated that winds have something to do with a storm being classified as "severe," although S-71 recognized that a severe storm could "possibly" contain hail. One Geography 1900b section interviewee (S-95) said that "your wind speed is higher" in a "severe" storm, but could not think of anything else that would make a storm "severe." Only one Geography 1900b section interviewee (S-103) stated that hail has something to do with it. One Geography 1900a section interview (S-9) stated that a "severe" thunderstorm is caused by "rapid rising and falling of air," and that "there's high winds."

Two of the three Geography 1900a section interviewees (S-9 and S-85), three of the four Geography 1900b section interviewees (S-103, S-114, and S-169), one Geography 1900c section interviewee (S-71), and the Geography 1900d section interviewee (S-83) incorrectly stated that lightning has something to do with a storm being classified as "severe." S-9 said that there is the "potential for lightning to touch." S-71 said that a "severe" storm has "crazy lightning...enough to hit the ground." S-83 stated that a storm could be classified as "severe" if it has "lots of lightning." S-114 stated that there has to be twenty minutes of lightning for the storm to be classified as "severe," but this was likely influenced by one of the multiple choice options for Question 7 on the pretest/posttest (Appendix F). S-169 said that "there's a lot of lightning."

Two Geography 1900a section interviewees (S-9 and S-91), two Geography 1900b section interviewees (S-103 and S-169), and one Geography 1900c section interview incorrectly stated that rain and/or flooding have something to do with a storm being classified as "severe." S-9 stated that there has to be "more than gentle rain." S-71 incorrectly stated that a storm could be classified as "severe" if it has "wash-out conditions." S-169 stated that "there's a threat of downpours being more heavier," and it is "dark…very dark."

One Geography 1900a section interviewee (S-91) and one Geography 1900b section interviewee (S-103) incorrectly stated that "damage" has something to do with a storm being classified as "severe." While it is true that "severe" storms cause damage, *damage potential* is not a criterion that is used to classify a storm as "severe." S-91 said that a "severe" storm is characterized by "the intensity and maybe the possibility of more danger and damage" from wind and flooding. S-103 stated that "there could be hail [and] winds" in a "severe" thunderstorm, but also stated that "severe" means "more rain, more lightning...worse conditions that can do more damage to you."

*Question 3: What actions should teachers and students take if they are in a school when a tornado is approaching?* All three Geography 1900a section interviewees, all four Geography 1900b section interviewees, all three Geography 1900c section interviewees, and the Geography 19000d section interviewee were asked to explain what teachers and students should do when a tornado is approaching a school.

All Geography 1900a, Geography 1900c, and Geography 1900d section interviewees, and two of the four Geography 1900b section interviewees (S-95 and S-169) stated that it was important to get away from the windows. S-41 said that this makes sense because of "all the flying glass." S-89 said that "if there were all windows in that hallway, we wouldn't be sitting in that hallway." S-83 said that if there was not an interior room, "then get to the wall farthest away from the windows." One Geography

1900b section interviewee (S-103) said that it was important to "shut the blinds" and "close the doors."

All Geography 1900a, Geography 1900c, and Geography 1900d section interviewees, and three of the four Geography 1900b section interviewees (S-95, S-103, and S-114) stated that it was important to go to the "middle" of the building, the "center" of the building," the "central-most location," the "interior room in the building," or the hallway. A Geography 1900a section interviewee (S-85) gave the best explanation:

Go to the hallways...because the wind can't get to you, and then less chance of things flying up at you. If you're on the outside, that can collapse, or a window can break and hit with shatters of glass, and stuff like that.

One Geography 1900b section interviewee (S-169) stated that teachers should have students "line up at the door and go to the bathroom."

One Geography 1900a section interviewee (S-85) two Geography 1900b section interviewees (S-103 and S-114), two Geography 1900c section interviewees (S-41 and S-71) and the Geography 1900d interviewee (S-83) said that it was important for students to protect their heads or necks with their hands, arms, books or something hard.

Two of the Geography 1900c section interviewees (S-41 and S-89) said that it was important to sit down.

None of the interviewees said anything about a severe weather action plan, although one Geography 1900b section interviewee (S-114) stated that teachers should do "whatever the 'tornado warning' signs say."

*Question 4: Should the windows be opened when a tornado is approaching?* Two Geography 1900b section interviewees (S-103 and S-169), the three of the Geography 1900c section interviewees (S-41, S-71, and S-89), and the Geography 1900d section interviewee (S-83) correctly stated that the windows should not be opened when a tornado is approaching. All of them were asked to explain why. One of the Geography 1900b section interviewees, the three Geography 1900c section interviewees, and the Geography 1900d section interviewee were adequately able to do so. S-41 said, "I've heard that you're not supposed to do that. Because if you open the windows, it's letting all of the wind to get in through the windows." S-71 had been told that the doors to the outside of the building should be opened, but was able to explain why this was incorrect:

- S-71: [When I was in school, they] opened the doors, but I don't know if that was correct. Ha ha.
- Bob: Okay. Open all the doors to the outside?
- S-71: Yes. They did.
- Bob: Okay. Do you agree with that?
- S-71: Uh, I don't know if it was correct or not. It seemed kinda' crazy at the time.
- Bob: Okay.
- S-71: But...they opened all the hallway doors...
- Bob: I was gonna' ask you, "Should you open all of the windows?" So, the doors and windows is the same thing.
- S-71: Yeah.
- Bob: Do you doubt it?
- S-71: I don't know. I know there's something about pressure, but things could come flying in the doors that wouldn't have if the doors would have been in place!

S- 83 said, "Well, on the movies and stuff, they open the windows to equalize the pressure, but I don't think that's really gonna' matter... because you get debris! Flying debris from the wind." S-89 stated, "I believe the reason why they do it is because they think it's gonna' even out pressure. But, um, it really doesn't do that at all...um...it would just create...more wind and damage. 'Cause even if the tornado wasn't gonna' go over the school, it's gonna' be really windy around there. And then everything is gonna' get blown around." S-169 said, "They could shatter either way. I don't think that opening the windows would be my first thing. I think that I would just get the kids out." S-103 thought that it had been necessary to open the windows years ago, but improvements in ventilation have now made this practice obsolete:

I was always told that, um, the buildings nowadays have enough ventilation in them to where you don't have to open the windows... because you don't have to worry about the pressure trying to equalize and busting out the windows. One Geography 1900a section interviewee (S-91) and one Geography 1900b section interviewee (S-95) stated that the windows *should* be opened when a tornado is approaching. S-95 stated that the windows will get blown out if they are not opened "because you're gonna' have a different pressure on the outside from the inside." S-91 told a detailed and fascinating story about a personal experience that lead S-91 to incorrectly believe that the windows should be opened in order to equalize the pressure between the inside and outside of the building:

When I was in 6th grade, we were [riding a school bus] back from Cedar Point, and it got, like, completely black and it started down-pouring, and it went from just, like, beautiful nice hot day at Cedar Point to being, like, horrible rain and everything! So I just remember that we all shut the windows and everything, so it was raining so hard. And the bus driver couldn't see at all, so she pulled into a rest stop and we parked between a semi and a delivery truck, and...so we...she says, you know...there's screaming...we turn on the radio and everyone's screaming, and you can hear trees breaking. It was like trucks driving through! It was the craziest sounds ever! And we looked behind us and you could see this tornado coming out of the field behind the rest stop. And so the bus driver just starts screaming at everyone, "Get under the seats! Get under the seats! Get under the seats!" And we all climbed under our seats, holding on to our seats, and the bus, like, picked up and was, like, trying to move! Like, it was hitting the side of the semi-truck! And then all of the emergency windows on the bus blew off the bus, and the emergency, like, the exit thing on the top of the bus shot off the bus! And the bus flew down...dropped to the ground, and the semi-truck next to us fell over, and then we all just sat there shaking and everything. And the whole point of the story is all the windows shot open equalizing some of the pressure and letting it in. And that's when our bus had dropped.

One Geography 1900b section interviewee (S-114) was not sure whether or not to open the windows, but said that opening the windows "might have something to do with equalizing pressure, but I have no idea whether it's a good or bad thing."

Geosciences 2900

*Question 1: What is the difference between a severe weather "watch" and a severe weather "warning?"* All three Geosciences 2900 section interviewees (S-78, S-

79, and S-117) were asked to differentiate between a severe weather "watch" and a severe weather "warning," but only S-79 were adequately able to do so.

Two Geosciences 2900 section interviewees (S-78 and S-117) possessed a significant lack of knowledge about "watches" and "warnings." S-78 stated that a "watch" is issued when "they spotted one outside of your...or they think one's coming," but a "warning" is "when they actually spotted one in the surrounding county, or in your county." The difference between *thinking one is coming* and there *actually being one coming* was unclear. S-117 stated that a "watch" is issued when a storm has actually been seen, and a "warning" is issued when there is the "potential for that to happen."

Question 2: What is the difference between a thunderstorm that is "severe" and one that is not? All three Geosciences 2900 section interviewees were asked to differentiate between a thunderstorm that is "severe" and one that is not. Two of them (S-79, and S-117) stated that winds and hail are the only criteria used to classify a storm as "severe." Only S-79 stated that the winds have to be "strong." None of the interviewees stated that the hail has to be large. S-117 stated that "there's a lot of wind" and "lots of hail" in "severe" storms.

The remaining Geosciences 2900 section interviewee (S-78) incorrectly stated that a storm is classified as "severe" when there is "something that's gonna' cause damage," like hail, wind, or lightning that is "close to touching ground."

*Question 3: What actions should teachers and students take if they are in a school when a tornado is approaching?* All three Geosciences 2900 section interviewees were asked to explain what teachers and students should do when a tornado is approaching a school.

All three Geosciences 2900 section interviewees correctly stated that it was important to go to an area away from, or that is the farthest from, the windows.

All three Geosciences 2900 section interviewees stated that it is important to take students to the "inner-most part" of the building, the "center" of the building, or the hallway.

S-79 said that it was important for students to "crouch" and protect the head and neck with a book:

And then they have to sit down, and they're supposed to crouch...usually they're supposed to bring a book with them...but if they're in a class that doesn't have books, then the position is to protect your neck, bring your head down and wait until we get an all-clearance.

S-117 said that it is important to "get close to the ground."

Two of the three Geosciences 2900 section interviewees (S-79 and S-117) were sensitive to the importance of a severe weather action plan. S-79 said that the teacher should grab the attendance book, turn off the lights, and take roll while the students are quietly being moved away from the windows. This interviewee was therefore already considering the importance of keeping track of all of the children after they have left their desks. S-117 said, "We'd probably have practiced this."

*Question 4: Should the windows be opened when a tornado is approaching?* Only S-78 correctly stated that the windows should not be opened when a tornado is approaching because "all of that wind will come in and pick up" various objects, and they will "fly around." S-79 implied comprehension without directly saying that the windows should not be opened. This interviewee stated that students and teachers should move into an "area that has no windows and is free of other furniture and stuff that could potentially harm us.

# Benchmark MS.1

# Geography 1050

The drawings constructed by the three Geography 1050a section interviewees

(S-59, S-90, and S-139) and the seven Geography 1050b section interviewees (S-5, S-10, S-56, S-76, S-98, S-104, and S-122) are in Figure M.5.

Two of the three Geography 1050a section interviewees (S-90 and S-139) and three of the seven Geography 1050b section interviewees (S-5, S-98, and S-104) were able to give an adequate definition of an air mass. All of these interviewees stated that air masses are characterized by similar temperature and moisture properties, although S-5 used the term "precipitation" rather than humidity, and S-98 incorrectly stated that air masses are also characterized by pressure. The remaining Geography 1050a section interviewee (S-59) and the remaining four Geography 1050b section interviewees (S-10, S-56, S-76, and S-122) could not give a definition, or gave an inadequate definition. S-10 said, "I really don't know how to explain anything in this course." S-56 said, "Um…that's hard, because a mass of air is just an amount of air that is there. I mean, a lot. It could either be cold or warm." S-76 said, "Air mass is, like, the description of what type of weather it's gonna' be." S-122 said, "It's a large…air particle, I guess. Yes, it's very large! They're either warm or cold."

One of the seven Geography 1050b section interviewee (S-104) was able to explain how air masses form. This interviewee stated, "An air mass is a mass of air that takes on the characteristics of, uh, wherever it originated. Um...I think it's temperature...it's humidity, probably, if it goes over water..." None of the three Geography 1050a section interviewees were able to explain how air masses form. One Geography 1050a section interviewee (S-90) stated that an air mass from Canada would be cold because "it's way north" and "facing away from the sun," but could not explain that air masses are taking on the properties of the surfaces beneath them.

Two of the seven Geography 1050b section interviewees (S-5 and S-56) expressed a *thorough* knowledge about specific names given to air masses that influence the weather in Michigan. None of the Geography 1050b section interviewees expressed a thorough knowledge. S-5 described "polar" air masses that come from "closer to the



Figure M.5. Illustrations Related to Air Masses, Fronts, Pressure Systems, and Winds (Geography 1050 Interviewees).

poles" and are cooler, "tropical" air masses that come from the tropics, "maritime" air masses that come from the oceans and bodies of water, and "continental" air masses that are "an inland kind" of air mass. This interviewee was able to combine these four terms and identify "maritime polar," "maritime tropical," "continental polar," "continental tropical," and even "continental arctic" air masses. S-56 stated that "polar" air masses are cold, "maritime" air masses are muggy or moist, and "continental tropical" air masses come from the Gulf of Mexico and Florida, "continental polar" air masses come from the northern Pacific Ocean.

All three Geography 1050a section interviewees (S-59, S-90, and S-139) and three of the seven Geography 1050b section interviewees (S-76, S-98, and S-104) were able to identify specific names given to air masses that influence the weather in Michigan, but lacked knowledge and comprehension about certain aspects of these air masses. S-59 was able to identify "continental," "polar," and "tropical" air masses, but was unable to identify the "maritime" air mass. This interviewee stated that "continental polar" air masses from Canada influence the weather in Michigan during the winter, and "tropical over-water" air masses from Florida influence the weather in Michigan during the summer. S-76 was only able to identify "continental polar" and "maritime tropical" air masses. S-90 was able to identify cold "polar" air masses that come from Canada, but incorrectly thought that these air masses are humid. This interviewee was also able to describe air masses that move northward from the Gulf of Mexico and the Atlantic Ocean, but was unable to identify the name given to those air masses. S-98 was able to identify "continental" and "maritime" air masses, but stated that an air mass from Canada is called "sub-arctic continental," and an air mass from the northern Pacific Ocean is called "sub-arctic maritime." This interviewee also referred to "tropical" air masses as "sub-tropical." S-104 correctly stated that "maritime tropical" air masses come from the southern Atlantic Ocean, but incorrectly stated that lake-effect snow is caused by moist

"maritime polar" air masses moving into Michigan from the west. After being questioned further, however, S-104 changed to say that lake-effect snow is caused by "continental polar" air masses. S-139 correctly stated that "continental" air masses from the polar and arctic regions influence the weather in Michigan. However, statements about "maritime" air masses was made. S-139 also mentioned "sub-tropical" air masses that influence the weather in the mid-latitudes, but it was not clear whether the interviewee had knowledge that Michigan is located within the mid-latitudes.

Two of the seven Geography 1050b section interviewees (S-10 and S-122) were unable to identify specific names given to air masses that influence the weather in Michigan.

The five Geography 1050b section interviewees who were able to identify specific names of air masses (S-5, S-56, S-76, S-98, and S-104) were asked to identify the air mass over Michigan at the time of their respective interviews. All of them were able to do so. S-5 said, "I would say a continental polar. Because right now it seems to be dry out. It seems not too humid, or anything like that. And, uh, it's cooler out." S-76 identified the air mass as "continental polar" because "we're, like, more inland than...um...we're not like, as close to the water as, like, if we were in Texas or the Gulf or something... [The air mass] came from the north." S-98 identified the air mass as "continental polar" because the air was "cold" and "pretty dry." S-56 and S-104 identified the air mass as "continental polar," but did not explain why.

None of the Geography 1050a section interviewees was asked to identify the air mass over Michigan at the time of their respective interviewees.

Two of the three Geography 1050a section interviewees (S-59 and S-90) and three of the seven Geography 1050b section interviewees (S-56, S-98 and S-104) were able to explain the difference between an air mass and a front. All of these interviewees stated that a front is "the leading edge," "the beginning," or the "front part" of an air mass. The remaining Geography 1050a section interviewee (S-139) and the four remaining

Geography 1050b section interviewees (S-5, S-10, S-76, and S-122) could not adequately explain the difference. S-5 said, "Um...it's, like, the barrier of, like...oh! Yeah, like...hmm. I don't know exactly." S-10 said, "Uh...ha ha...I don't really know how to explain any of that stuff." S-76 said, "Air mass is, like, the description of what type of weather it's gonna' be, and a front is, like, the wind, like, the way it's blowing." S-122 said, "A front is actually...the system moving... It's the actual, um, air mass that's moving in, like if you have high flowing into a low. And it creates, like, a storm... A front is actually the storm. Or, your squall line is the storm." S-139 said, "A front is basically...uh... the difference in temperature that is moving into an area. And then an air mass is just a stationary air mass, in general... Well, they're both air masses."

All Geography 1050a section interviewees and all Geography 1050b section interviewees except S-98 were able to identify "cold" and "warm" as being two types of fronts that move through Michigan. Two of the seven Geography 1050b section interviewees (S-5 and S-10) expressed misconceptions about these fronts, however. S-5 stated that fronts are associated only with low pressures systems, but incorrectly stated that the fronts could be "anywhere" in that area. S-10 stated that a warm front is associated with a high pressure, and a cold front is associated with a low pressure. Two of the three Geography 1050a section interviewees (S-90 and S-139) could not explain the difference between the two fronts, but could describe how fronts are drawn on weather maps.

Two of the three Geography 1050a section interviewees (S-59 and S-90) and six of the seven Geography 1050b section interviewees (S-5, S-10, S-56, S-76, S-104, and S-122) expressed knowledge about the existence of stationary fronts. Both of the Geography 1050a section interviewees (S-59 and S-90) were able to explain what a stationary front is, but only one of the Geography 1050b section interviewees (S-5) was able to do so. S-5 said, "Stationary fronts are fronts that don't really move anywhere.

It's, like, two cold and warm fronts that, like, came together but aren't really going anywhere. They're just staying stationary." S-59 said, "A stationary is drawn on the map with triangles on one side and little half circles on the other, and it just means that it's not moving anywhere." This interviewee stated that a stationary front would "become either a warm front or a cold front" if it started to move. S-90 stated that "the stationary is when two fronts come together and they don't move. It's kinda' at a standstill."

Two of the three Geography 1050a section interviewees (S-59 and S-90) and five of the seven Geography 1050b section interviewees (S-10, S-56, S-76, S-104, and S-122) expressed knowledge about the existence of occluded fronts, but only one Geography 1050b section interviewee (S-122) was able to explain what an occlusion is. This interviewee stated, "As the cold front is moving in, it's gonna' squeeze your warm air...'cause you warm air is gonna' flow up and over, and it's gonna' actually occlude." One Geography 1050a section interviewee (S-90) appeared to possess some knowledge at first, but ultimately failed to explain what an occlusion is. This interviewee stated, "Occluded is...when one side's over the top...er, no... I can't remember what occluded is."

One Geography 1050a section interviewee (S-90) stated that warm fronts will produce steady, light to moderate precipitation as they move through Michigan, while cold fronts will produce severe, but short duration, storms. This interviewee stated that "there's gonna' be more violent weather" (such as thunderstorms) as a cold front "comes in," and "it's more like you get a drizzle" along a warm front. Another Geography 1050a section interviewee (S-59) stated that "the cold front brings the severest of weather." However, this interviewee incorrectly stated that "usually you have sunny…not too many clouds in the sky" along a warm front. The remaining Geography 1050a section interviewee (S-139) stated that the "condensation of a cold front moving into a warm front causes the precipitation," but it was unclear what the interviewee meant by this. No

statements about the types of weather associated with warm and cold fronts were made by the Geography 1050b section interviewees.

All Geography 1050a section interviewees and six of the seven Geography 1050b section interviewees (S-5, S-10, S-56, S-76, S-98, and S-122) stated that air moves from high to low pressure.

Five of the seven Geography 1050b section interviewees (S-5, S-10, S-56, S-104, and S-122) stated that the winds in the Northern Hemisphere circulate clockwise around a high pressure and counter-clockwise around a low pressure. One Geography 1050b section interviewee (S-76) incorrectly thought that the rotation was counter-clockwise around both a high *and* a low. The remaining Geography 1050b section interviewee (S-98) and two of the three Geography 1050a section interviewees (S-90 and S-139) made no statements about winds rotating around high and low pressure systems in the Northern Hemisphere. The remaining Geography 1050a section interviewee (S-59) reversed them and incorrectly thought that the winds rotate counter-clockwise around a high and clockwise around a low.

One Geography 1050b section interviewee (S-98) mentioned the coriolis effect. This interviewee stated, "Okay, the winds would be going predominantly from high to low, but since it's Northern Hemisphere, it's also gonna' curve slightly to the right because of coriolis force, I think." S-98 however, did not make statements about what *causes* the coriolis effect.

Four of the seven Geography 1050b section interviewees (S-5, S-56, S-104, and S-122) stated that air is rising at a low pressure and sinking at a high pressure. Only S-5 referred to this as a "convection current." Three of the seven Geography 1050b section interviewees (S-56, S-98 and S-104) stated that the air is converging at the low and diverging at the high, although S-56 did not use the term "converging" to explain what is happening at the low, and S-122 did not directly state that the air is diverging at a high but explained that the air "converges from the high into the low." None of the three
Geography 1050a section interviewees made statements about rising and sinking air at high and low pressure systems.

Two of the three Geography 1050a section interviewees (S-59, S-90) and five of the seven Geography 1050b section interviewees (S-5, S-10, S-56, S-98, and S-122) incorrectly associated temperature with pressure systems. The two Geography 1050a section interviewees and three of the five Geography 1050b section interviewees (S-5, S-10, and S-56) thought that cold air is associated with low pressure systems and warm air is associated with high pressure systems. None of these interviewees could explain why this association was made, although S-59 implied that it was cooler at a low pressure system because it was rainy. Two Geography 1050b section interviewees (S-56 and S-98) thought that warm air is associated with low pressure systems and cold air is associated with high pressure systems. Neither of these interviewees could explain why this association was made. S-139 was the only interviewee who correctly stated that there is not always a direct relationship between temperature and surface pressure. This interviewee stated, "The temperature doesn't depend on the pressure system. The temperatures depend on the seasons."

Two of the three Geography 1050a section interviewees (S-59 and S-139) and three of the seven Geography 1050b section interviewees (S-98, S-104, and S-122) were able to describe the precipitation patterns associated with high and low pressure systems, although minor misconceptions were expressed by S-139. When asked whether a high or low pressure was near Michigan at the time of the interview, S-59 stated that there was a low pressure "because it's kinda' rainy." S-98 stated that "lows have stormier weather. It can rain in highs and stuff, it's just not as common. So I'm just guessing that it's nicer weather in the high pressure...more likely to be rain, or precipitation, in the low pressure." S-104 said that there is "nicer weather" at a "high pressure zone." When asked why it is cloudy at a low, this interviewee responded that the air mass is brought up "to its dew

point level, and then once it's up there, it will condense and form clouds or precipitation or whatever." S-122 stated that highs "are clear, sunny weather, and your lows are associated with...uh...the storms" because the air "is converging. It's rising. It's...ah...as the air rises, it cools and condenses and precipitates." S-139 stated that there is "condensation...rain...stormy areas...rainstorms...[and] rainy areas...with low pressure, generally," and "with high pressure system you have usually have no clouds, clear skies, sunny." For unclear reasons, however, this interviewee associated pressure systems with particular regions of the country: "You usually find the high pressure system in the Great Plains area. The low pressure system [is] in Indiana and Michigan."

Four of the seven Geography 1050b section interviewees (S-56, S-76, S-98, and S-104) stated that Michigan is located in a westerly wind belt. However, only S-76 and S-104 were able to explain how an air mass from either the north or the south could move over Michigan. S-76 stated that a cold air mass that "came from the northwest...blows... counter-clockwise in the northern hemisphere." This interviewee did not directly state that this counter-clockwise motion was around a low pressure system, but knowledge was implied. S-104 was at first unable to explain how air masses from the north or the south could move over Michigan, but was finally able to come up with a correct explanation after constructing the drawing in Figure M.5h. None of the three Geography 1050a section interviewees stated that Michigan is located in the westerly wind belt.

None of the interviewees made statements about jet streams.

None of the interviewees referred to a low pressure system as a "cyclone" or a high pressure system as an "anticyclone," but one Geography 1050a section interviewee (S-59) stated that "one is a cyclone and the other is the anti-cyclone. But honestly, I don't know [which is which]."

#### Geography 1900

The drawings constructed by the three Geography 1900a section interviewees (S-9, S-85, and S-91) and the four Geography 1900b section interviewees (S-95, S-103, S-114, and S-169) are in Figure M.6. The drawings constructed by the three Geography 1900c section interviewees (S-41, S-71, and S-89) and by the Geography 1900d section interviewee (S-83) are in Figure M.7.

Two of the three Geography 1900a section interviewees (S-9 and S-85) and two of the four Geography 1900b section interviewees (S-103, and S-114), and one of the three Geography 1900c interviewees (S-71) were able to give an adequate definition of an air mass. None of these interviewees, however, were able to fully explain how air masses are characterized, and S-71 had no conception of how large the air mass has to be in order to be classified as such. The best definition was given by S-103, who stated that an air mass is "a body of air that contains certain characteristics that distinguish it from another body of air." This interviewee stated that air masses are characterized by temperature, but also thought that air masses are characterized by pressure and precipitation contained within the air mass. S-9 stated that an air mass has similar temperatures across it, but did not know that it also has similar moisture content, and incorrectly thought that air pressure and wind direction are factors used to categorize air masses. S-85 stated that an air mass is an "area of air" that moves from "one area to another," but made no statements about how air masses are characterized. S-114 stated that an air mass is a "huge body of air," but then stated that pressure differences distinguish one air mass from another. When asked to explain this, the interviewee said, "Maybe it has something to do with cooler air. It may indicate lower pressure, whereas drier air... Uh...like, [air masses are characterized by] what's in the air, maybe." S-114 even stated that a warm air mass would change into a different air mass at night because the temperature gets cooler at night.

One of the three Geography 1900a section interviewees (S-91), two of the four



Figure M.6. Illustrations Related to Air Masses, Fronts, Pressure Systems, and Winds (Geography 1900a and Geography 1900b Interviewees).



Figure M.7. Illustrations Related to Air Masses, Fronts, Pressure Systems, and Winds (Geography 1900c and Geography 1900d Interviewees).

Geography 1900b section interviewees (S-95 and S-169), two of the three Geography 1900c section interviewees (S-41 and S-89), and the Geography 1900d section interviewee (S-83) expressed little to no knowledge about what an air mass is. S-41 said that an air mass is "a big cloud of air. S-83 stated that temperature is a factor in how an air mass is classified, but defined an air mass as "air that's got the same pressure around it. S-89 thought that the air in the interview room could be classified as an air mass. When asked how air masses are classified, this interviewee said, "I don't know." S-91 said that an air mass is "particles grouped together." When asked to explain this, the interviewee said, "Well...we talked about air masses as far as the particles that are involved in air... Like oxygen and carbon dioxide." S-95 said, "I...couldn't tell you exactly what it is, or anything." S-169 redundantly stated that an air mass is "a mass of air," and thought that different elevations and altitudes are what distinguish one air mass from another.

Only one Geography 1900a section interviewee (S-9) and one Geography 1900c section interviewee (S-71) made statements about how air masses form. S-9 stated that an air mass from Canada would be colder and drier than an air mass over the Pacific Ocean because "most of Canada is land" and "[the air mass] over the Pacific is coming over water so it would have different moisture content." However, this interview did not comprehend that air masses over the ocean are moister *because they are over water*. The interviewee thought that an air mass over the Pacific Ocean has higher moisture content *because it is warmer* than an air mass over Canada, and therefore is "able to hold more moisture." There was apparently no conception that a warm air mass is not always a moist air mass. S-71 stated that air masses from Canada and the northern Pacific Ocean are cold, but incorrectly stated that an air mass over the Pacific Ocean is warmer "because it's closer to the equator." The interviewee also stated that air masses over the Gulf of Mexico are warm, but incorrectly stated that the air mass over the Gulf of Mexico is the "warmest." This interviewee therefore had some conception about

the effect latitude has on the formation of an air mass, but had no conception about the effect the oceans and continents have. Also, it was unclear why this interviewee thought that an air mass over the Gulf of Mexico is warmer than an air mass over Mexico.

None of the interviewees made statements about specific names given to air masses that influence the weather in Michigan. Therefore, none of the interviewees were asked to identify the air mass over Michigan at the time of their interviews. However, two Geography 1900b section interviewees (S-103 and S-114) and one Geography 1900c section interviewee (S-71) made general statements about the air mass over Michigan on the mid-April days that each was interviewed. S-71 stated that "warmer air was coming through" because "the air temperature seems to be warming." The outdoor temperature was 57°F during the time of the interview. S-103 stated that "this is a slightly warm air mass that doesn't contain very much moisture," and that it is coming from the south-west because the air is moving from the sub-tropical high to the sub-polar low. S-114 stated that it was a "warmer" air mass "because the sun is out." The outdoor temperature was between 55°F and 60°F during both interviews.

All three Geography 1900a section interviewees (S-9, S-85, and S-91), two of the four Geography 1900b section interviewees (S-103 and S-114), one of the three Geography 1900c section interviewees (S-41), and the Geography 1900d section interviewee (S-83) were able to explain the difference between an air mass and a front. All except S-103 stated that a front is "the edge," "the leading edge," "the beginning," or the "edge" of an air mass. S-103 stated that a "warm front [is] where...the warm air was moving into the cold air," and was able to illustrate on a drawing (Figure M.6e) that the front is the leading edge of an air mass. S-114 at first thought that a front is the temperature of the air mass, "either cold or warm," and the air mass is "just air itself." However, the interviewee later stated that it makes more sense to say that a front is only the leading edge of the air mass.

Two of the four Geography 1900b section interviewees (S-95 and S-169) and two of the Geography 1900c section interviewees (S-71 and S-89) had trouble explaining the difference between a front and an air mass. S-71 stated that a front is "the changing of the weather... [For example,] warm air [can move] over the mass of air. So it's moving over an area." This interviewee also incorrectly stated that the difference between a front and an air mass is that a front is only the temperature, but an air mass "could probably be, like, a whole bunch of different things." S-89 nearly quoted one of the incorrect multiple choice options for Question 10 on the pretest/posttest (Appendix F): "A cold front is...[the] amount of cold air...coming before a big front of warm air...like, if the cold comes first and then the warm air." When asked what a front is, S-95 said, "I don't know. I have never had a weather class." This interviewee, however, was able to explain where fronts are found: "Where, like, warmer air is moving in...like, if you have a warm front, and warmer air is moving in. And if you have a cold front, then the colder air is moving in." S-95 was also able to describe what fronts look like on weather maps: "A cold front has got the triangles, and I think the warm front has got the...half moons." S-169 was also unable to give a definition of a front, but was able to give an example: "A cold front is where a cold air mass is...taking over a warm mass."

Two of the three Geography 1900a section interviewees (S-9 and S-85), three of the four Geography 1900b section interviewees (S-95, S-103, and S-169), the three Geography 1900c section interviewees (S-41, S-71, and S-89) and the Geography 1900d section interviewee (S-83) were able to identify "cold" and "warm" as being two types of fronts that move through Michigan. However, S-41 was unable to explain anything about them, S-71 and S-83 thought that a front is between a high pressure and a low pressure and did not know how to differentiate between where a cold front would be and where a warm front would be, and S-89 stated that a cold front is "a big amount of pressure coming in." The two Geography 1900a section interviewees (S-103 and S-169) expressed misconceptions

about these fronts. S-9 thought that a warm front is the leading edge of warm air moving out of a low pressure, and a cold front is the leading edge of cold air moving out of a high pressure. S-85 thought that a cold front determines where a high pressure is, and a warm front determines where a low pressure is. S-103 stated that a "warm front [is] where...the warm air was moving into the cold air." However, this interviewee also stated that air moves from high to low pressure, and that cold air is associated with high pressure and warm air is associated with low pressure. When asked to explain how warm air could move into cold air to form a warm front, S-103 responded, "That's a good question. I don't think I can answer that." S-169 was able to illustrate what cold fronts and warm fronts look like on a weather map (Figure M.6g), but was unable to place them within the context of pressure systems.

None of the interviewees made statements about the existence of either stationary or occluded fronts.

None of the interviewees stated that warm fronts will produce steady, light to moderate precipitation as they move through Michigan, while cold fronts will produce severe, but short duration, storms. However, one Geography 1900a section interviewee (S-9) believed that precipitation is "more likely" at a cold front because the air is moving into an area "that has less moisture, and a drop in the temperature [is] making it more likely to rain. So the cold front moves through and that's what drops the temperature. The warmer air goes above and the colder air goes below…" S-9 added that precipitation is "less likely" at a warm front. This interviewee therefore and had no conception that warm air is also rising at the warm front.

Two of the four Geography 1900b section interviewees (S-103 and S-114), the three Geography 1900c interviewees (S-41, S-71, and S-89) and the Geography 1900d section interviewee (S-83) stated that air moves from high to low pressure. One Geography 1900b section interviewee (S-95) knew that the winds move either from high to low pressure *or* low to high pressure, but was not sure which. Another Geography

1900b section interviewee (S-169) made no statements about the existence of high and low pressure systems, and said that air moves "from a high to low temperature."

Two of the three Geography 1900a section interviewees (S-85 and S-91) stated that the winds circulate around pressure centers, although both S-85 and S-91 incorrectly thought that the winds rotate clockwise around a low pressure and counter-clockwise around a high pressure in the Northern Hemisphere. The three Geography 1900c section interviewees (S-41, S-71, and S-89) and the Geography 1900d section interviewee (S-83) correctly stated that the winds circulate clockwise around a high pressure and counterclockwise around a low pressure. S-41 stated that the wind "would not be as strong" at a high pressure, but thought that it was because "it's moving toward the low pressure."

Two of the three Geography 1900c section interviewees (S-41 and S-89) stated that, in the Northern Hemisphere, air is deflecting to the right as it comes out of a high pressure because of the coriolis effect. However, neither could explain why. When asked what the cause of the coriolis effect is, S-41 said, "I don't know."

Two of the three Geography 1900a section interviewees (S-85 and S-91) and two of the four Geography 1900b section interviewees (S-103 and S-114) stated that air is rising at a low pressure and sinking at a high pressure. Only S-114 referred to this as a "convection current."

Two of the three Geography 1900a section interviewees (S-9 and S-85), two of the four Geography 1900b section interviewees (S-95, and S-103), and one of the three Geography 1900c section interviewees (S-71) made an incorrect association between temperature and pressure. This incorrect association led S-9 and S-85 to incorrectly state that cold and warm fronts are lines that separate the high and low pressures. S-71 stated that a high pressure is associated with higher temperatures and a low pressure is associated with lower temperatures, but then added that "it might be reversed." S-95 and S-103 stated that warm air is associated with low pressure and cold air is associated with a high pressure, but S-95 expressed uncertainty about whether or not this was actually

correct. S-89 implied that a high pressure is associated with cold weather by stating that a cold front is "a big amount of pressure coming in."

The Geography 1900d section interviewee (S-83) was able to describe the precipitation patterns associated with high and low pressure systems. This interviewee stated that "clear and calm weather" is associated with a high pressure and "clouds" and "storms" are associated with a low pressure. However, this interviewee made inaccurate statements about *why* such weather occurs: "With highs, there's so much air pressure that the water couldn't evaporate into the sky…and then low pressure…there's not a lot of pressure, so the water could evaporate into the sky." Two of the Geography 1900a section interviewees (S-85 and S-91) incorrectly thought that a recent storm that deposited 4 to 5 inches of snow in Kalamazoo was caused by a high pressure system. As evidence for this, S-85 pointed out that the air was cold, and S-91 explained that the wind occurred because a high pressure system was pushing into a low pressure zone. Both interviewees incorrectly stated that "good" or "less active" weather is associated with a low pressure system.

All three Geography 1900a section interviewees (S-9, S-85, and S-91), two of the four Geography 1900b section interviewees (S-103 and S-114), and the Geography 1900d section interviewee (S-83) stated that Michigan is located in a westerly or south-westerly wind belt. However, none of these interviewees had any idea how an air mass from either the north or the south could move over Michigan. When asked how an air mass from the north could move into Michigan if the prevailing winds are westerly, S-83 stated, "Uh...maybe the jet stream." S-85 stated that it has to do with "all the [global] wind belts" moving northward and southward. However, no statements were made that low pressure systems can pull warm air masses northward and cold air masses southward. S-103 stated that the sub-polar low is north of Michigan and a sub-tropical high is south of Michigan; therefore, some air masses were moving into Michigan from the south-west because they were moving from the high pressure to the low pressure. This interviewee,

however, could not explain how air masses could move into Michigan from directions other than south-west.

Only the Geography 1900d section interviewee (S-83) mentioned the jet stream, although this interviewee had no conception about what it is.

None of the interviewees referred to a low pressure system as a "cyclone" or a high pressure system as an "anticyclone."

# Geosciences 2900

The drawings constructed by the three Geosciences 2900 section interviewees (S-78, S-79, and S-117) are in Figure M.8.

All three Geosciences 2900 sections interviewees were able to give an adequate definition of an air mass. All of them stated that an air mass is characterized by similar or uniform temperature and humidity, although S-78 incorrectly thought that air masses could also be characterized by pressure properties. S-78 and S-117 stated that an air mass moves from one place to another.

One of the three Geosciences 2900 section interviewees (S-117) made statements about how air masses form. This interviewee stated that an air mass "adapts the characteristics of the land features it's over... [For example,] if it's over water, it's gonna' pick up...moisture," and "if it's over a dessert for a long time, it's gonna' start to be...warmer, perhaps."

One of the Geosciences 2900 section interviewees (S-79) expressed a thorough knowledge about specific names given to air masses that influence the weather in Michigan. This interviewee stated the Michigan's weather is predominantly influenced by "continental polar, which can come down from Canada. Or, maritime tropical which can come up from the Gulf or the Atlantic depending on where it starts and the type of winds that move it. Or from the northeast, which would...be...maritime polar."

Another Geosciences 2900 section interviewees (S-78) expressed some



Figure M.8. Illustrations Related to Air Masses, Fronts, Pressure Systems, and Winds (Geosciences 2900 Interviewees).

knowledge of specific names given to air masses that influence the weather in Michigan, but lacked knowledge about certain aspects of these air masses. This interviewee stated that there are "maritime polar" and "continental polar" air masses, but said nothing about the "tropical" air masses. This interviewee also expressed uncertainty about whether a "continental polar" air mass would become a "continental maritime" air mass after it crosses the Great Lakes. The interviewee finally decided that a "continental polar" air mass would remain a "continental polar" air mass.

Both of the Geosciences 2900 section interviewees who were able to identify specific names of air masses (S-78 and S-79) were asked to identify the air mass over Michigan at the time of their interviews. The temperature was below freezing and lakeeffect snow was falling during both interviewee sessions. Only S-78 was able to correctly identify the air mass as "continental polar," but even this interview at first incorrectly stated that a "maritime polar" air mass was over Michigan because it came down "from the north over the large land mass, bringing all the cold air down this way," and "because Michigan is surrounded by the Great Lakes." The interviewee, however, realized that the air mass would have to come "from the ocean" for it to be classified as "maritime," so changed to identify the air mass as "continental polar." S-79 stated that "if [the air mass] came from the northeast...it would be maritime polar," but if it came "from Canada, then it would be continental polar, but it would have picked up moisture over Lake Michigan." However, the interviewee was never able to identify whether the air mass was "continental polar" or "maritime polar." This was surprising because, as explained above, this interviewee gave a thorough explanation of the types of air masses that influence the weather in Michigan.

All interviewees were able to explain the difference between an air mass and a front. All of them stated that a front is the "leading edge" or the "leading boundary" of an air mass, or that the air mass is behind the front. S-79 even stated that it is the leading edge of a *warm or cold* air mass.

All interviewees were able to identify "cold" and "warm" as being two types of fronts that move through Michigan. However, all of them expressed misconceptions about these fronts. S-78 and S-117 thought that a warm front is the leading edge of warm air moving out of a low pressure, and a cold front is the leading edge of cold air moving out of a high pressure. S-79 drew the fronts backwards from what they should be, and drew the cool and the warm air in incorrect positions near the warm front (Figure M.8b). When ask why the fronts were drawn with the half circles facing south and half triangles facing east, the interviewee responded, "I could have drawn them [the other way]. I guess it depends on where your air mass is coming from." However, neither the drawing nor the comments made by the interviewee indicate any conception about "where [the] air mass is coming from."

One of the three Geosciences 2900 section interviewees (S-117) made statements about the existence of stationary fronts. This interview, however, failed to recognize that a stationary front is one that is generally not moving: "I think it's when...cold and warm fronts meet. If two air masses came together."

None of the interviewees made statements about the existence of occluded fronts.

None of the interviewees stated that warm fronts will produce steady, light to moderate precipitation as they move through Michigan, while cold fronts will produce severe, but short duration, storms.

One of the three Geosciences 2900 section interviewees (S-117) stated that air moves from high to low pressure, and only one of the three Geosciences 2900 section interviewees (S-78) stated that the winds rotate counter-clockwise around a low pressure and clockwise around a high pressure in the Northern Hemisphere. S-78 stated that "high pressure is moving toward the low pressure area." However, no knowledge that the *air* is moving from high to low pressure was expressed. S-79 stated that there is a counterclockwise "spin" at a low pressure system, but the interviewee's drawing incorrectly showed air moving *into* the low in the north-west quadrant and *out of* the low in the

remaining quadrants (Figure M.8c). S-117 was unable to explain how air circulates around pressure systems. This interviewee had no conception that air moves from high to low pressure, but incorrectly thought that this was because "it's usually colder" at a high pressure.

None of the interviewees mentioned anything about the coriolis effect.

S-79 stated that air is rising at a low pressure and sinking at a high pressure. This interviewee stated that "when arm air is rising, it's creating an area of low pressure." No statements were made, however, about other factors that could cause an area of low pressure.

Two of the three Geosciences 2900 section interviewees (S-78 and S-117) made an incorrect association between temperature and pressure. Both of these interviewees thought that warm air is associated with low pressure and cold air is associated with a high pressure.

None of the interviewees were able to describe the precipitation patterns associated with high and low pressure systems. S-117 incorrectly stated that it could be "less cloudy" at a low pressure area, and "more cloud-coverish" at a high pressure area. This interviewee also wrongly thought that a storm forms because "the high pressure [is] taking over a low pressure system."

Two of the three Geosciences 2900 sections interviewees (S-78 and S-79) stated that Michigan is located in a westerly wind belt. However, neither of them was able to explain how an air mass from the north or the south could get into Michigan.

S-79 made statements about the jet stream, but these statements did not reflect knowledge about them: "I don't know enough abut the jet streams, but I don't think that the jet streams would influence [the movement of air masses] that much because [jet streams are] higher strong winds in the atmosphere."

S-79 referred to a low pressure system as a "mid-latitude cyclone." None of the interviewees referred to a high pressure system as an "anticyclone."

#### Benchmark MS.2

### Geography 1050

*Question 1: What happens to your ears when you move from lower to higher elevations or altitudes in the troposphere*? Two of the three section Geography 1050a interviewees (S-59 and S-139) and all seven of the Geography 1050b section interviewees (S-5, S-10, S-56, S-76, S-98, S-104, and S-122) were asked a variant of the question, "What happens to your ears when you move from lower to higher elevations or altitudes in the troposphere?" All of them stated that their ears would pop. When asked to explain why, all of them stated that it has something to do with atmospheric pressure, but only one Geography 1050a section interviewee (S-59) and one Geography 1050b section interviewee (S-98) could adequately explain why. S-59 said that the ears would pop because "there's air inside your ear canal, and, uh, when it pops, it's trying to equalize the pressure inside your head." S-98 said, "There'd be a higher pressure inside your ears, and the air needs to get out." One Geography 1050a interviewee (S-90) was not asked this question.

*Question 2: What is the relationship between atmospheric pressure and elevation or altitude in the troposphere?* All three Geography 1050a section interviewees and all seven Geography 1050b section interviewees were asked to state the relationship between atmospheric pressure and elevation or altitude. All three Geography 1050a section interviewees and five of the seven Geography 1050b section interviewees (S-56, S-76, S-98, S-104, and S-122) stated that atmospheric pressure decreases with an increase in elevation and/or altitude. One Geography 1050b section interviewee (S-5) was not sure how atmospheric pressure changes with elevation. Another Geography 1050b section interviewee (S-10) thought that the atmospheric pressure *increases* with elevation.

All three Geography 1050a section interviewees and two of the five Geography 1050b section interviewees who stated that atmospheric pressure decreases with an

increase in elevation or altitude (S-98 and S-104) were able to adequately explain why atmospheric pressure decreases with height. However, one Geography 1050b section interviewee (S-56) admitted, "I don't know [why]. I just memorized these concepts." Two of the Geography 1050b section interviewees who were able to explain why atmospheric pressure decreases with height (S-98 and S-104) clarified their explanations with a drawing. These drawings are in Figure M.9. Both interviewees used dots to show



Figure M.9. Illustrations for Why Atmospheric Pressure Decreases with Height (Geography 1050 Interviewees).

the atmosphere getting thinner with increasing elevation, although much fewer dots make this difficult to see in the drawing constructed by S-98.

*Question 3: What is the relationship between air temperature and elevation or altitude in the troposphere?* Two of the three Geography 1050a section interviewees (S-59 and S-90) and six of the seven Geography 1050b section interviewees (S-5, S-10, S-56, S-76, S-98, and S-122) were asked to explain how air temperature changes with respect to elevation or altitude. All of them stated that air temperature decreases with an increase in elevation or altitude, although S-59 wrongly thought that the atmospheric layer closest to the ground is the stratosphere. One Geography 1050a section interviewee (S-139) and one Geography 1050b section interviewee (S-104) were not asked this question.

None of the interviewees were able to adequately explain why air temperature decreases with height. Four of the Geography 1050b section interviewees (S-5, S-10, S-76, and S-122) directly stated that they did not know why. One Geography 1050a section interviewee (S-59) and one Geography 1050b section interviewee (S-56) made no attempt to explain why. One Geography 1050b section interviewee (S-98) stated that air temperature decreases in the mountains "because the sun's light is coming down and heating the earth...and then as you get up [in the mountains] it's colder because you're farther away from the earth." One Geography 1050a section interviewee (S-90) stated that air temperature drops in the mountains "because you're not getting as much radiation from the ground." This interviewee also stated that "there was less oxygen" in the mountains, but thought that this is because "there isn't any trees" up there.

### Geography 1900

Question 1: What happens to your ears when you move from lower to higher elevations or altitudes in the troposphere? All Geography 1900a, Geography 1900b, Geography 1900c, and Geography 1900d section interviewees were asked a variant of the

question, "What happens to your ears when you move from lower to higher elevations or altitudes in the troposphere?" All of them stated that their ears would "pop" or "get plugged." The three Geography 1900a section interviewees (S-9, S-85, and S-91), two of the four Geography 1900b section interviewees (S-104 and S-114), and the Geography 1900d section interviewee (S-83) were able to adequately explain why. S-9 said, "It's equalizing pressure between the tubes that are in your ears and what you are experiencing on the outside." S-83 said, "With a higher elevation, the pressure is lower. So...they want to equalize, because there's gonna' be a higher pressure in the ear." S-85 stated that ears pop because "there's less pressure, and that throws off the equilibrium." The three Geography 1900c section interviewees stated that it has something to do with pressure, but were unable to explain why.

*Question 2: What is the relationship between atmospheric pressure and elevation or altitude in the troposphere?* All Geography 1900a, Geography 1900b, Geography 1900c, and Geography 1900d section interviewees were asked to state the relationship between atmospheric pressure and elevation or altitude. All three Geography 1900a section interviewees, three of the four Geography 1900b section interviewees (S-95, S-103, and S-114), two of the three Geography 1900c section interviewees (S-41 and S-89) and the Geography 1900d section interviewee (S-83) said that atmospheric pressure decreases with an increase in elevation and/or altitude.

One Geography 1900a section interviewee (S-91), one Geography 1900b section interviewee (S-103), and the Geography 1900d section interviewee (S-83) were able to adequately explain why atmospheric pressure decreases with height. S-83, for example, gave the following explanation while constructing the drawing in Figure M.11b:

Okay. So, if you're on the mountain which is like a thousand feet... So, you've got all of this air pushing down on you. You have just this... (student draws the two uppermost arrows)...if you're up here... (student draws the stick person at the top of the mountain). But if you have this... (student draws the stick person at the bottom of the mountain and the

*lowermost arrow*)...then you have this part and this part...(*student points to all three arrows*). So there's more pushing down. So there's more pressure.

Three Geography 1900b section interviewees (S-95, S-103, and S-114) directly stated that they did not know why. S-95 added, "I know there's a reason. I have a diagram of it in my book." Two Geography 1900a section interviewees (S-9 and S-85) suggested that it has to do with gravity. S-9 said that the pull of gravity is getting "less strong as you get higher up in the atmosphere, so it has less hold over the oxygen." S-85 simply stated that there is "more gravity" at lower elevations. One Geography 1900c interviewee (S-71) incorrectly thought that the pressure increases with elevation because "the air molecules are really separated down here, and it's warmer. And as you go up higher, they're gonna' be really close together, 'cause they're [colder]." A drawing constructed by this interviewee (Figure M.11a) clearly shows a belief that air molecules are more tightly packed at higher elevations. Two Geography 1900c interviewees (S-41 and S-89) incorrectly thought that the pressure decreases with height because air temperature decreases with height. S-41 stated that the pressure is lower in the mountains because it's colder, "so it causes the molecules to...spread apart." S-89 constructed the drawing in Figure M.11c and stated that pressure is decreasing because "the molecules are moving out and away from each other, 'cause they're cooling, so they're beginning to fall back down."

One Geography 1900b section interviewee (S-169) incorrectly stated that atmospheric pressure *increases* with elevation.

One Geography 1900a section interviewee (S-91) and one Geography 1900b section interviewee (S-103) clarified their explanations with a drawing. These drawings are in Figure M.10. Both drawings illustrate that the air has a higher density at lower elevations and altitudes. The drawing by S-91 illustrates more air "pushing down" at lower elevations. The longer arrow represents more air pushing down, and the shorter arrow represents less air. The drawing by S-103 illustrates that the air is "more

condensed" near the earth's surface. The arrows represent gravity, the darker inner circles represent a higher density, and the lighter outer circles represent a lower density. It is unclear what the diagonal line represents.

*Question 3: What is the relationship between air temperature and elevation or altitude in the troposphere?* Three of the four Geography 1900b section interviewees (S-95, S-114, and S-169), the three Geography 1900c section interviewees, and the



Figure M.10. Illustrations for Why Atmospheric Pressure Decreases with Height (Geography 1900a and Geography 1900b Interviewees).



Figure M.11. Illustrations for Why Atmospheric Pressure Decreases with Height (Geography 1900c and Geography 1900d Interviewees).

Geography 1900d section interviewee were asked to explain how air temperature changes with respect to elevation or altitude. All of them stated that air temperature decreases with an increase in elevation and/or altitude. Only S-114 was able to explain why air temperature decreases with elevation or altitude. This interviewee stated, "Um…because…as air rises…it expands." S-41 and S-71 made no attempt to explain why. S-83 simply said, "Because air pressure…it can't hold as much…I don't know." S-89 thought that air temperature decreases with height because higher levels are "not soaking up as much of the sun's rays." This interviewee stated that "the ground is absorbing all the sun's rays… [The] whole surface is ground. And up there in the mountain, it's just one, like, rock that's up in the air. It's not surrounded by other things that are absorbing it." S-169 thought that it has something to do with the fact that it can be 80 degrees on the mountain "but there's still snow on the top of the mountain." S-95 said that is has something to do with the fact that the air molecules "move slower" at higher elevations.

#### Geosciences 2900

*Question 1: What happens to your ears when you move from lower to higher elevations or altitudes in the troposphere?* All three Geography 2900 section interviewees (S-78, S-79, and S-117) were asked a variant of the question, "What happens to your ears when you move from lower to higher elevations or altitudes in the troposphere?" All of them stated that their ears would pop. When asked to explain why, all of them stated that it has something to do with atmospheric pressure, but only S-79 was able to explain why.

*Question 2: What is the relationship between atmospheric pressure and elevation or altitude in the troposphere?* All three Geosciences 2900 section interviewees were asked to state the relationship between atmospheric pressure and elevation or altitude.

One of them (S-79) stated that atmospheric pressure decreases with an increase in elevation or altitude.

S-79 was able to adequately explain why atmospheric pressure decreases with height. A drawing constructed by S-79 (Figure M.12a) illustrates that, at higher elevations, "the molecules of gases are spreading apart farther and farther, so they're not putting as much pressure on you," while at lower elevations, "you got lots of air



Figure M.12. Illustrations for Why Atmospheric Pressure Decreases with Height (Geosciences 2900 Interviewees).

molecules pressing down on you so you have greater pressure." S-78 and S-117 stated that atmospheric pressure *increases* with an increase in elevation. S-78 thought that pressure is higher on the mountains because "it's colder" in the mountains. S-117 stated that higher pressure on the mountains has something to do "with the distance," but could not explain what this meant. This interviewee was therefore asked to clarify the comment with the drawing. This drawing is in Figure M-12b, and is very similar to what was constructed by S-91 for the Geography 1900a class section (Figure M.10a). Unlike S-91, however, S-117 is unable to explain the drawing. S-117 incorrectly believed that there is greater pressure on the mountain even though a smaller line is drawn. It is therefore likely that the interviewee simply reproduced an image that was remembered from class.

*Question 3: What is the relationship between air temperature and elevation or altitude in the troposphere?* All three Geosciences 2900 section interviewees were asked to explain how air temperature changes with respect to elevation or altitude. All of them stated that air temperature decreases with an increase in elevation or altitude.

None of the interviewees were able to adequately explain why air temperature decreases with height. S-78 made no attempt to explain why. S-117 said, "I don't remember [why]." S-79 gave an excellent description of what happens to molecules when there is an input of energy, but was unable to explain why air temperature decreases:

- S-79: Now as [air molecules] gain energy...it can come from the sun; it can come from the earth's surface features. It depends on where they are found... So they're gaining heat energy...and as they're gaining heat energy, they begin to hit each other...and they're moving apart. And so instead of having all of these air molecules compressed into one area, you have them moving around and bouncing off each other... so that they're not as tightly packed together.
- Bob: Are you saying they're spreading apart because they're being heated up?
- S-79: They're gaining heat energy, so they're spreading out.

Bob:	So if they're gaining heat and they're spreading out, why is
	itwell, let me ask this question: what happens to the
	temperature as you go higher up?

S-79: It's decreasing. So why is it gaining heat energy and decreasing [in temperature] at the same time?

Bob: Yeah.

S-79: (*Silence for 14 seconds.*) Well, at some point that's gotta' stop, though. At some point, you're gonna' hit a point where it starts to cool again.

### Benchmark MS.3

# Geography 1050

One of the three Geography 1050a section interviewees (S-90) and two of the seven Geography 1050b section interviewees (S-56 and S-104) stated that a cloud exists in the form of a liquid. Two Geography 1050a section interviewees (S-59 and S-139) and three Geography 1050b section interviewees (S-76, S-98, and S-122) incorrectly stated that a cloud exists in the form of water vapor, or as water in a gaseous state or form. Two Geography 1050b section interviewees (S-5 and S-10) expressed no ideas about what state a cloud exists in. S-5 made no direct statements about this, but did state that a cloud is "probably from water evaporating off the earth, or whatever, and condensating, like, at high altitude." S-10 admitted having no idea what a cloud is.

The two Geography 1050a section interviewees (S-59 and S-139) and two of the three Geography 1050b section interviewees (S-76 and S-122) who stated that a cloud exists in the form of a gas or as water vapor were asked to explain the contradiction that the water vapor in the cloud could be seen, but the water vapor in the air around them could not be. S-59 said, "I think it's just more dense [in the cloud]." S-76 said, "Cause it...so much is, like, pushed together [in the cloud], I guess. I don't know, 'cause the way...I couldn't tell you." S-122 said, "Because it's colder outside. It's cold up there...at the elevation." S-139 said, "You kinda' can [see the water vapor around us]. If

you're steaming some water, you can see the water vapor rise. A cloud is kinda' the same thing only the molecules are only a little bigger."

Two of the three Geography 1050a section interviewees (S-90 and S-139) and four of the seven Geography 1050b section interviewees (S-56, S-98, S-104, and S-122) stated that, in order to get a cloud, the air has to cool to the dew point.

Two of the three Geography 1050a section interviewees (S-90 and S-139) and three of the seven Geography 1050b section interviewees (S-5, S-56, and S-98) stated that warm air can contain more water vapor than cold air.

One of the three Geography 1050a section interviewees (S-59) and three of the seven Geography 1050b section interviewees (S-10, S-98, S-104) mentioned the necessity of condensation nuclei or particulate matter.

One of the three Geography 1050a section interviewees (S-90) and one of the seven Geography 1050b section interviewees (S-5) were able to provide an adequate explanation for how clouds form. S-5 stated that water is evaporating off the earth, that the air cools as it rises, that the air has to cool in order to get a cloud, and that water is condensing at high altitudes. However, this interviewee expressed a misconception that the air has to cool to *below* the dew point in order for condensation to occur, and said nothing about the importance of condensation nuclei. S-90 adequately explained the major aspects of cloud formation, but also said nothing about the importance of condensation swere expressed by this interviewee.

Two of the three Geography 1050a section interviewees (S-59 and S-139) and six of the seven Geography 1050b section interviewees (S-10, S-56, S-76, S-98, S-104, and S-122) were troubled with an overall inability to explain how clouds form. S-10 had no idea how a cloud forms, except that condensation nuclei, or "particles in the air," has something to do with it. S-56 thought that condensation occurs because a pocket of warm air "gets smaller" when it rises because "it's getting into colder temperatures." This interviewee also stated that a warm pocket of air is not cooling as it rises, but rather is

being cooled by the cooler air around it at the higher altitudes. S-59 stated that "water vapor clings to [particulate matter]," but also thought that a cloud is "just water vapor in the sky." S-76 stated that a cloud "could be water," but, when asked how the water gets to higher altitudes, responded, "It's just up there." This interviewee later changed to say that a cloud exists in the form of a gas. This interviewee also stated that you "can have clouds if it's clear; they're just not rain clouds." S-98 stated that the relative humidity has to be at 100% for clouds to start forming, but could not explain how the temperature would cool for this to occur. S-104 stated that "a cloud is where an air mass reaches its dew point and condenses onto condensation nuclei" and that "it starts out as a gas, and then condenses into water." However, this interviewee did not explain how this process could occur. S-122 correctly stated that "the air rises...cools, condenses, and forms your cloud," but also stated that a cloud is not the result of condensation, but rain is the result of condensation and a cloud is a gas. S-139 correctly stated that the temperature can fall to the dew point of the air mass because of a "lack of heat. Nighttime comes, and the temperature drops." However, this interviewee had no conception that the air could also cool by rising. This interviewee also thought that the dew point rises at night.

### Geography 1900

One of the three Geography 1900a section interviewees (S-9), two of the four Geography 1900b section interviewees (S-95 and S-103), and two of the three Geography 1900c section interviewees (S-41 and S-71) stated that a cloud exists in the form of a liquid. One of the Geography 1900b section interviewees (S-169) admitted having no idea what a cloud is. One Geography 1900c section interviewee (S-89) and the Geography 1900d section interviewee (S-83) did not make direct statements about what state or form a cloud exists in. S-83 said that clouds have particulate matter, moisture, and "condensation caused by cooling." S-89 stated that clouds have "evaporated particles coming together and cooling and condensing." Two of the Geography 1900a

section interviewees (S-85 and S-91) and one of the Geography 1900b section interviewees (S-114) incorrectly stated that a cloud exists in the form of water vapor, or as water in a gaseous state or form.

The two Geography 1900a section interviewees (S-85 and S-91) and the Geography 1900b section interviewee (S-114) who stated that a cloud exists in the form of a gas or as water vapor were asked to explain the contradiction that the water vapor in the cloud could be seen, but the water vapor in the air around them could not be. S-85 said, "I'm just guessing that it's more condensed up there." S-91 said, "Maybe it's just the... I don't know. There has to be some kind of water vapor in it that makes it visible." S-114 said, "Perhaps because it's more concentrated in the sky because the pressure...it might have to do with pressure differences."

Two of the three Geography 1900a section interviewees (S-9 and S-91), two of the four Geography 1900b section interviewees (S-95, and S-103), the three Geography 1900c interviewees (S-41, S-71, and S-89), and the Geography 1900d section interviewee (S-83) stated that, in order to get a cloud, the air has to cool. One Geography 1900a section interviewee (S-91), one Geography 1900c section interviewees (S-89), and the Geography 1900d section interviewee (S-83) stated that the air has to cool to the dew point, although S-83 and S-89 were only able to identify the dew point after being given hints by the interviewer.

One of the Geography 1900b section interviewees (S-103) stated that warm air can contain more water vapor than cold air.

One of the three Geography 1900a section interviewees (S-85), two of the four Geography 1900b section interviewees (S-95, and S-169), one of the three Geography 1900c section interviewees (S-71) and the Geography 1900d section interviewee (S-83) mentioned the necessity of condensation nuclei or particulate matter, although S-169 could not explain the role that particulate matter plays in the formation of a cloud. S-83 even referred to one of the Geography 1900 labs in which students had to create a cloud

in a bottle using hot water, ice, and matches. This interviewee stated, "Like, the dust and stuff. Like, when we did the experiment with the smoke."

One Geography 1900c section interviewee (S-41) provided an adequate explanation for how clouds form. This interviewee stated that "you get a cloud from water evaporating from the surface and condensing in the air…into tiny droplets," that heat causes the molecules to expand and the air to rise, and that condensation occurs when there is cooling due to elevation. However, this interviewee made no statements about the importance of condensation nuclei.

Two of the three Geography 1900a section interviewees (S-9 and S-91), two of the four Geography 1900b section interviewees (S-95, and S-103), one of the three Geography 1900c section interviewees (S-89) and the Geography 1900d section interviewee (S-83) were able to provide an adequate explanation for how clouds form, but also possessed misconceptions about certain aspects. S-9 gave an excellent description of the process of condensation, and even gave an example of what happens when a soda can is pulled out of the refrigerator: "The pop can is cooler than the air and it drops the air around it past the dew point, so water condenses onto the can." This interviewee, however, expressed a misconception that the temperature has to cool to below the dew point in order to get a cloud. S-83 stated that a "cloud is formed when you have...the particulate matter... You have to have that. And you have to have moisture. And you have to have condensation caused by cooling." This interviewee also stated that cooling occurs when heat causes the air to rise, but incorrectly said that the air will cool down once it reaches "a [certain] level." S-83 apparently failed to recognize that the air is constantly cooling as it moves upward. S-89 stated that a cloud "is formed through the process of condensation, evaporated particles coming together and cooling and condensating...because, uh, they're rising." However, this interviewee was only able to identify the dew point *after* being given a hint by the interviewer. S-89 was then able to state that the dew point "is the amount of saturation in the air," but also wrongly thought

that the dew point is "probably a percentage" like the relative humidity. S-91 stated that water evaporates into the air, that the air is warmed by the sun heating the ground, that warm air will rise because it is "less dense," and that the rising air will cool to the dew point and form a cloud. However, this interviewee also believed that a cloud exists in the form of a gas because "I was on an airplane yesterday, and we were flying all the way through clouds. I didn't see any water being stuck, like to the window." S-95 gave excellent descriptions of the importance of evaporation from surface water, the role of the sun as the ultimate source of energy, and the process of atmospheric convection. S-95, however, expressed a misconception that precipitation is not only the rain and snow that is falling from the cloud, but is also the water in the cloud. S-103 stated that water in the form of a gas is being added to the air through evaporation, and that water droplets collect in the atmosphere to form a cloud when the temperature falls to a "certain point." However, this interviewee never used the term "condensation" and thought that "once you pass the dew point, you will have precipitation. It can be in the form of a cloud. It can be snow. It can be rain. Or sleet." S-103 thought that the temperature has to cool to *below* the dew point in order to get a cloud, and referred to the dew point as the "condensation" point.

One of the three Geography 1900a section interviewees (S-85), two of the four Geography 1900b section interviewees (S-114 and S-169), and one of the three Geography 1900c section interviewees (S-71) were troubled with an overall inability to explain how clouds form. S-71 believed that as the air cools at higher elevations, the molecules become closer together because the pressure is higher. A cloud therefore forms when the "molecules [become] close enough together." S-85 stated that the "water evaporates on the earth and rises up, and then it gathers, pools, and condenses." However, this interviewee made no statements about how condensation occurs, or even about what it is. S-114 thought that a cloud is "basically a collection of water vapor" that has been "squeezed out the air." This interviewee made no statements about how this

could happen, and also stated that a cloud exists in the form of a gas. S-169 had absolutely no idea how a cloud forms even though a reference was made to one of the Geography 1900 labs in which students had to create a cloud in a bottle using hot water, ice, and matches. This interviewee stated, "I don't know. Well...we had water at the bottom of the jar. We lit a match, and we put the match out in the water, and the smoke came off and it was collected in the jar."

## Geosciences 2900

Two of the three Geosciences 2900 section interviewees (S-78, and S-79) stated that a cloud exists in the form of a liquid. S-117 at first appeared to believe that a cloud exists in the form of water vapor, and even stated that "when it's too heavy, it can't hold it anymore, and the *water vapor* comes down in a form of precipitation" [emphasis mine]. However, this was contradicted in the next sentence when it was stated that "the *water* comes down [and] it goes into a, uh, collection point usually" [emphasis mine]. It is therefore unclear what state this interviewee believed that a cloud exists in.

Two of the three Geosciences 2900 section interviewees (S-79, and S-117) stated that, in order to get a cloud, the air has to cool to the dew point, although S-79 referred to it as the "condensation point." One interviewee (S-78) did not make statements about the air cooling as it rises, but thought that a cloud forms because the pressure "gets higher and higher, so, like, you can't fit in anymore space."

None of the interviewees directly stated that warm air can contain more water vapor than cold air, but S-117 stated that the dew point is based on "the amount of moisture in the air," and that the air has to cool to the dew point for a cloud to form.

Two of the three Geosciences 2900 section interviewees (S-79 and S-117) mentioned the necessity of condensation nuclei or particulate matter.

One of the three Geosciences 2900 section interviewees (S-117) was able to provide an adequate explanation for how clouds form. This interviewee adequately

explained almost all aspects of cloud formation, including water evaporating into the air from a source at the surface, the sun being the ultimate energy source, the air molecules spreading out when heated, the air rising and cooling to the dew point, the necessity of particulate matter, and the development of precipitation. The only aspect that this interviewee expressed uncertainty about was whether a cloud exists in the form of water or water vapor.

One of the three Geosciences 2900 section interviewees (S-79) was able to provide an adequate explanation for how clouds form, but also possessed misconceptions about certain aspects. This interviewee stated that water vapor can change into a liquid when it cools, that warm air rises, and that condensation nuclei are necessary for cloud formation. However, S-79 incorrectly stated that the air starts to cool only *after* it rises t a "certain point" in the atmosphere. S-79 also stated that condensation occurs "when the gas can no longer maintain the energy level that it had before... And so you're going from a gas which has a higher state of energy to a liquid that has a lower state of energy." However, it was unclear whether the interviewee had knowledge that warm air can contain more water vapor than cold air.

One of the three Geosciences 2900 section interviewees (S-78) was troubled with an overall inability to explain how clouds form. This interviewee stated that water vapor evaporates into the air, but thought that a cloud forms when the pressure increases to the point where there is not enough space in the air to hold the water vapor.

# Benchmark MS.4

## Geography 1050

None of the three Geography 1050a section interviewees and none of the seven Geography 1050b section interviewees were able to define what an "ozone action day" is. One of the three Geography 1050a section interviewees (S-139) and four of the seven Geography 1050b section interviewees (S-10, S-56, S-98, and S-104) claimed either that they had never heard of an "ozone action day" before taking the pretest/posttest, or that they had heard of it but did not know what it is. S-10 did not own a TV and wondered if they talked about "ozone action days" on NPR (National Public Radio). S-56 guessed that an "ozone action day" is a day that people should not be outside. S-98 admitted having heard of an "ozone action day," but did not know what it was. S-104 only remembered it from the pretest/posttest:

Well, I'm assuming it has something to do with...well, I mean...it's pretty obvious that it has something to do with, you know, try to cut back on whatever. To be honest with you, this is stuff I'm remembering from your test questions.

S-139 claimed to be from mid-Northern Michigan where "ozone action days" are not regularly issued.

Two of the three Geography 1050a sections interviewees (S-59 and S-90) and three of the seven Geography 1050b section interviewees (S-5, S-76, and S-122) thought that an "ozone actions day" was issued for the purpose of protecting the ozone layer above the earth. S-5 said that people need to be careful and watchful about what is going on with the ozone because there are "holes in it," and there are "various pollutants that you use that could damage it." S-76 thought that an "ozone action day" would be issued "when the sun rays are bad." This interviewee declared that an "ozone action day" is not "a good day to be outside because there's nothing protecting you," and that gas from cars would ruin the ozone layer by "open[ing] it up" and "mak[ing] a bigger hole." S-90 said that people should not mow lawns or drive cars as much on "ozone action days," but was not sure why except that "it won't help the crisis with the ozone layer." S-122 said that, on hot days, people should not fill the gas tanks of cars because the fumes could do more damage to the ozone. When asked how this would happen, the interviewee said that "the carbons…mix with the oxygen in the air, and it attacks the O<sub>3</sub> that's there and it breaks it down." S-59 said that people should not pump gas "in highly populated cities," but thought that the purpose of this was to stop the destruction of the ozone layer above the earth.

None of the three Geography 1050a section interviewees and none of the seven Geography 1050b section interviewees stated that human activities create ground-level ozone, or that the effects of ground-level ozone can have an adverse effect on human health.

### Geography 1900

None of the three Geography 1900a section interviewees and none of the four Geography 1900b section interviewees was able to define what an "ozone action day" is. One Geography 1900b section interviewee (S-103) stated that "ozone action days" have something to do with "reactions" that can take place:

Well, I know about the ozone. I don't know exactly the relationship between...I know, like, the chlorofluorocarbons...what they do to that...the atmosphere...the protective, um...the protective ozone that we have...I'm not exactly sure about the relationship. To me, I believe it has something to do with, um, the reactions that can take place. Because I know that with chemical reactions, heat can kind of act as a catalyst...and so I think that this has something to do with it, although I don't know the certain...I don't know everything that's involved. That's just what I...my little understanding.

One Geography 1900b section interviewee (S-114) and two of the three

Geography 1900c section interviewees (S-41 and S-89) claimed to have never heard of an "ozone action day" before taking the pretest/posttest.

All three Geography 1900a section interviewees (S-9, S-85, and S-91) and one of the four Geography 1900b section interviewees (S-95) thought that an "ozone action day" is issued for the purpose of protecting the ozone layer above the earth. S-9 stated correctly stated that people should not pump gas or run a lawn mover on "a really hot day during the summer" but thought that this was because these actions could deplete the
ozone layer. This interviewee mentioned the Antarctic region as an example and said, "There's a hole. We don't want it. That's more sun, though." S-85 correctly said that people should not fill their gas tanks or drive their cars on hot and humid days but incorrectly stated that this was because these actions might adversely affect the ozone that is "pretty far" up "over the area in which you live." This would result in the sun's radiation being "greater on the earth...and it'll become almost poisonous, or something like that, and very...not good for the human body." S-95 said that when an "ozone action day" is issued, people should "cut down on things" that are polluting the ozone layer, such as burning trash and filling gas tanks. According to this interviewee, pollutants are actually opening the ozone and "exposing part of it to outer space." S-91 correctly stated that you should not pump gas on an "ozone action day," but thought that this was for the purpose of protecting the ozone layer that surrounds the earth:

Someone told me on campus last year that it was one of those days, and I was just, like, "Oh! Okay!" She said you weren't supposed to get gas today, or something like that. I said I was going to get gas, and she said, "You're not supposed to today." You're supposed to try to keep all of the fumes out of the air for one day because it's certain...something with radiation that makes it more...it's more impacting, or something like that, like, on that day because of some reason. They didn't really know how to explain it that well. It's just that we weren't supposed to because...it would affect [the ozone] more because...it didn't have some protective layer, or something on that day for some reason.

When asked where the ozone was at that was being "affected," the interviewee said that it was "very high," and that the fumes would "float up" to this ozone "through convection."

One of the four Geography 1900b section interviewees (S-169) and one of the three Geography 1900c section interviewees (S-71) thought that an "ozone action day" was issued in order to *reduce* the amount of ozone that is going into the ozone layer. S-71 stated that "we're adding the bad stuff, making, possibly, the ozone layer thicker," and that this is "letting in all the bad rays from the sun, and it's not letting them back out." S-71 also stated that pollution is "clogging the atmosphere," which is "causing the hotter

temperatures to stay close to the earth so they can't get out." S-169 asked, "Isn't there ozone around the earth, and it's because of the pollution?"

In similar fashion to the Geography 1050 section interviewees, none of these interviewees stated that human activities create ground-level ozone, or that the effects of ground-level ozone can have an adverse effect on human health. The Geography 1900d section interviewees (S-83) stated that people should not mow lawns or fill the gas tanks of cars on "ozone action days" because "the smog and the pollution in the air make it dangerous." After being asked why the advisory is called an "ozone action day," however, the interviewee expressed uncertainty about whether the problem was ground level ozone or the depletion of the ozone layer around the earth:

Um, well ozone is  $O_3$ . I know that. I don't know if it's because, like, they don't want to make the hole in the ozone layer bigger. Or, that the smog and everything creates ozone. Because I know ozone is harmful to breathe, I think.

## Geosciences 2900

None of the three Geosciences 2900 section interviewees were able to define what an "ozone action day" is.

S-117 thought that an "ozone actions day" is issued for the purpose of protecting the ozone layer above the earth. This interviewee stated that pollution needs to be reduced by activities such as car pooling, but that the reason for this was so that "we don't send as much up to deplete the ozone" in the stratosphere, which is "two or three layers up."

S-78 stated that "ozone action days" are issued on hot and humid days when "you probably try to conserve stuff." However, this interviewee did not know that the main pollutant of concern is ozone.

None of the Geosciences 2900 section interviewees stated that human activities create ground-level ozone, or that the effects of ground-level ozone can have an adverse

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effect on human health. However, S-79 initially expressed some valid concepts about ground level problems. This interviewee stated that it was important not to pump gas, let cars idle, or use tractors and "equipment like that" because heat and fumes "are so intense" that these activities are "increasing the heat." These fumes "aren't able to rise because of the humidity factors and the heat factors," and the main concern is about contributing to the "gas and things that are produced here." However, this interviewee did not mention ground level ozone. When asked why the advisory is called an "ozone action day," the interviewee expressed the notion that such days are issued in order to protect the ozone layer above the earth:

I'm assuming because it puts stress on the ozone layer. And because the gases that are involved with the ozone tend to be gases that are given off by cars and engines, and such.

Appendix N

Human Subjects Institutional Review Board (HSIRB) Approval Letter

Date: August 25, 2004

To: Joseph Stoltman, Principal Investigator Robert Ruhf, Student Investigator for dissertation

From: Amy Naugle, Ph.D., Interim Chair

Re: HSIRB Project Number 04-08-06

This letter will serve as confirmation that your research project entitled "Analyzing the Effects of Inquiry-Based Instruction on the Learning of Earth Science among Pre Service Teacher Education Students" has been **approved** under the **exempt** 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: August 25, 2005

This approval letter and the letters for the two annual re-approvals that were granted on August 2005 and August 2006 are on file at the offices of the Human Subjects Institutional Review Board (HSIRB) of Western Michigan University:

> The Research Compliance Coordinator 251W Walwood Hall Western Michigan University Kalamazoo, Michigan 49001

The title of this dissertation as it appeared on the original approval letter ("Analyzing the Effects of Inquiry-Based Instruction on the Learning of Earth Science Among Pre Service Teacher Education Students") was changed to the current title ("Analyzing the Effects of Inquiry-Based Instruction on the Learning of Atmospheric Science Among Pre-Service Teacher Education Students") on all re-approval letters.

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