SCHOOL SCIENCE AND MATHEMATICS

VOLUME 107
NUMBER 1
JANUARY 2007

Official journal of the School Science and Mathematics Association
Founded 1901

IN THIS issue

Editor's note

In the past three issues, we have made a few changes in the format and content of the Journal. This month begins a new volume year and you will notice two more significant changes. The cover for this year has been revised with the hope of reflecting a more academic appearance in line with the journal contents. We are also revising the SSMJ web site to reflect new content and to make it easier for authors to track the progress of their manuscripts, and for reviewers to submit manuscript reviews. The web site be found at ssmj.tamu.edu. Finally, In This Issue will be added each month to preview the journal contents in a format and language that is intended to be readable by a general audience, and provide an quick overview and summary of the contents.

Research in Brief

Teachers' Classroom Questions

Alpaslan Sahin

This review summarizes recent research on the role of questions and the many purposes they serve for teaching. In particular, the author discusses the importance of guiding and probing questions in the light of the current focus on student-centered instruction. He provides characteristics of guiding and probing questions, calling for further research in this area.

Research Articles

Preparing Preservice Math Teachers for Diverse Students

Jayne A. Downey and Georgia A. Cobbs

Unique field assignments were created for an Elementary Math Methods course to provide students with experiences with diverse learners. Analyses suggested that the follow-up interviews with the future math teachers provided them with insights into the learning needs of diverse students. The authors propose way to help preservice teachers to continue becoming more aware of culturally relevant teaching strategies.

Field Investigations to Align School Science with Contemporary Science

Mark Windschitl, Amy E. Ryken, Margaret Tudor, Gary Koehler, & Karen Dvornich,

Unlike controlled experiments in school science textbooks, scientists routinely select naturally occurring events and conditions and look for descriptive, correlative, or causal trends. The authors describe the range of field investigations conducted by scientists and K-12 students and describe a model of three different types of field investigations that are more representative of current scientific practice. These investigations can provide rigorous and engaging inquiry experiences for young learners.

Elementary and middle school students' mental models of simple circuits

Michael Jabot and David Henry

The authors developed written assessments to probe students' understanding and mental models of direct current (DC) circuit concepts. Students' increased consistency in describing a single direction of current flow coincided with grade 4 instruction on batteries and bulbs. However, the proportion of students using a bi-directional flow model was similar in grades 3-8.

Problem Section

Beginning this month, the Problem Section moves to the web site. We will continue to include in the printed journal the directions for contributing to the section, along with a few of the newly posed problems. Be sure to visit the newly-designed SSMJ web site at ssmj.tamu.edu to read the problem section. As in the past, the archived Problem Sections can also be found on the web site.

A Comparative Model of Field Investigations: Aligning School Science Inquiry with the Practices of Contemporary Science

Mark Windschitl
Karen Dvornich
University of Washington

Amy E. Ryken
University of Puget Sound

Margaret Tudor
Pacific Education Institute

Gary Koehler
Washington Department of Fish and Wildlife

Field investigations are not characterized by randomized and manipulated control group experiments, however most school science and high-stakes tests recognize only this paradigm of investigation. Scientists in astronomy, genetics, field biology, oceanography, geology, and meteorology routinely select naturally occurring events and conditions and look for descriptive, correlative, or causal trends. Field investigations contribute to scientific knowledge by describing natural systems, noting differences in habitats, and identifying environmental trends and issues; they are designed to answer an investigative question through the systematic collection of evidence and the communication of results. This paper describes the range of field investigations conducted by scientists and K-12 students and elaborates a comparative model of three different types of field investigations (descriptive studies, comparative studies, correlative studies). These forms of investigation are more representative of current scientific practice and provide rigorous and engaging inquiry experiences for young learners.

Purpose

In an effort to align school science standards with the practices of contemporary science, this study was designed to build a comparative model of three different types of field investigations (descriptive studies, comparative studies, correlative studies) and relate each type to the essential features of inquiry. Two questions guided the research: 1) Is there more to scientific inquiry than hypothesis testing? and 2) What is the relationship between inquiry and field investigation? In this paper we share the comparative model we developed from our research with natural resource agency and university scientists and two school sites engaged in field investigations. Our intent is to share the model we developed and advocate that schools and state science assessments move beyond the controlled experiment as the only form of inquiry to include a wider range of inquiry models.

A Brief Background to School Science Inquiry

Two of the key assumptions in current school science are that scientists conduct investigations by 1) *actively manipulating variables* and generally *controlling all conditions* in an experimental setup, and 2) that investigations always support or refute causal relationships (as opposed to non-causal correlations, the kinds of relationships with which so many contemporary sciences are concerned).

This thinking is a result of the dominance of physics research in the development of paradigms of inquiry for school science, dating back to the early twentieth century. Student exposure to these methods of science began in the 1880's with the widespread adoption of the "laboratory method" of instruction (Owens, 1985) in which manipulation and direct control of variables was featured. Pioneered by German chemists, laboratory instruction made its way into higher education within American universities. Newly-formed high schools, with their desire to emulate the intellectual work of colleges and universities soon followed (Rudolph, 2004; Tolley, 2003). Before a decade had passed, the "laboratory method" was seen as a mechanism "destined to revolutionize education" in the words of one observer (Griffin, 1892). In such experiments popular at the time and still practiced in schools today, the physical systems being investigated were relatively simple, there were few variables to be concerned with, and interactions among variables could be defined in a straightforward way with deterministic formulae. There was a generic and inflexible scientific method that began with a clear hypothesis and ended with statements about significant differences between groups. The view of science inquiry characterized by these assumptions does not resemble what many scientists are doing today.

Science Education Standards: Science as Inquiry

Current state and national science education standards encourage instruction that focuses on problem-solving and inquiry; activities which characterize the pursuits of scientists (AAAS, 1993; NRC, 1996, 2000; NSTA, 1995). Focusing on "science as inquiry" (NRC, 1996) is one way to help students learn that, "science is not a fixed body of knowledge but an evolving attempt by humans to create a coherent description of the physical universe" (White, 2003, p. 174). The standards (NRC, 1996) emphasize that students

> develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (p.105)

Classroom inquiry has been associated with a number of different pedagogical approaches, including hypothesis testing, practical problem-solving, modeling, thought experiments, doing library research, engaging in Socratic dialogue, discovery learning, and projects. Of all these activities, hypothesis testing is perhaps most closely associated with the work of scientists (albeit incorrectly). Currently, the predominant form of hypothesis testing described in state standards, practiced in schools, and assessed in high stakes tests is that of a *controlled experiment*. In this form of inquiry, students begin by hypothesizing about links between variables in a system. For example, students might hypothesize that small crystals of salt will dissolve in water faster than large crystals of salt, because of the greater surface area to volume ratio of the smaller crystals. What follows then is the design of an experiment, what many teachers call a "fair test," comparing two conditions that differ only on a single variable (in this case, between two beakers of water with different size crystals in each). Students would identify a *responding* or *dependent* variable (the rate at which the crystals dissolve or the time it takes to dissolve), the *manipulated* or *independent* variable (the size of the crystals), and a set of *controlled* variables to assure that no other influence could reasonably affect the responding variable (e.g., the temperature of the water, the volume of water in the beakers, the amount of stirring). Students then compare how fast the crystals dissolve under these controlled conditions and draw the appropriate conclusions. Although many teachers and students are familiar with this procedure, promoting this model of inquiry as the exclusive representative of how science works is a misrepresentation that ignores much of how new knowledge is produced, particularly in the contemporary biological sciences.

Field Investigation as Inquiry

Analyses of practice in scientific communities have shown that there is no universal research method and that scientific inquiry can take a variety of forms (Alters, 1997; Feyerabend, 1993; Harwood, 2004; Knorr-Cetina, 1999; McGinn & Roth, 1999). Building explanations, or "providing causes for effects and establishing relationships based on evidence and logical argument" (NRC, 1996, p. 145), is central to the work of all scientists. Procedurally, some scientists do formulate and then test hypotheses; other scientists, however, construct their hypotheses only after data analysis, and still other scientists, such as field biologists, astronomers, or anatomists, conduct descriptive research in which hypotheses may not be explicitly tested (Latour, 1999;1987).

In the biological sciences in particular, the systems being studied are complex and variables often interact in probabilistic ways. Many studies must be done in the natural environment, because the simple act of "reproducing" natural phenomena in the laboratory may distort how that phenomena occurs (e.g., history shows us how lab experiments on animals to test their learning capacity vastly underestimated how intelligently these creatures performed in their natural surroundings). Perhaps most importantly, many scientists, particularly those who do field work, do not actively manipulate variables and maintain "control" and "experimental" groups. Scientists in astronomy, genetics, field biology, oceanography, geology, and meteorology routinely create models of phenomena not by controlling conditions, but rather by selecting naturally occurring observations and looking for descriptive, correlative, or causal trends in those observations. (See

Anderson and Lindzey (2003), Gillespie and Allen (2004), Goodin, Gao and Hutchinson (2004), and Pinho et al. (2004) for published examples of field investigations).

Indeed, these researchers *may* be looking for cause and effect relationships through differences between two sets of observations, but these observations do not arise from controlled situations *per se*.

As an example, a researcher may be interested in the relationship between air quality and the growth of lichens on trees. In her study, she would not be able to manipulate air quality around entire groves of trees. Rather, this researcher would identify areas of high air pollution (perhaps near a freeway or an industrial area) and areas of low air pollution. Then she would consider how to take into account potentially confounding variables such as species of trees, rainfall in the area, or amount of sunlight. She would then select similar trees for study that were living in comparable conditions, except of course for their location in an area of high or low air pollution, and compare the amount of lichen growth, thus choosing one focus variable to be measured in each of the "two groups" of trees.

Another difference between field studies and traditional control group studies is that field studies often do not assume that there is a causal relationship between variables. The relationship may be one of correlation, but not necessarily causation. To recall our recent example, lichens may not grow as well on certain species of trees in areas of high air pollution, but it may well be that a *third variable* such as the amount of local precipitation, influences *both* the degree of air pollution and the growth of lichens on trees. Indeed, our researcher may not want to identify two discrete areas of high and low air pollution, but rather, test all trees available for both amount of lichen coverage and quality of air in that specific location. Correlations (statistically represented as an "r" value and often graphically represented in scatter plots) between two continuous variables would then be determined to ascertain if there were positive, negative, or no association.

In addition to causal (or merely comparative) and correlational studies, scientists also conduct investigations in which they try to create a purely descriptive model of some natural phenomena. This is often done in newly-developing fields of science where not enough is known to suggest plausible hypotheses about causal relationships (Latour, 1999, 1987). One such type of study is the tracking of cougars through their habitats with radio collars. A typical question might be simply, "Where do cougars spend most of their time?" or, "How is their range overlapping with areas developed by humans?" Another example of a descriptive study is creating a profile of the presence of macro-invertebrates along the length of a river. To answer these questions, scientists then choose measurable or observable variables to guide data collection. These types of studies result in averages, medians, ranges, that "tell a descriptive story" and often generate enough data to help pose meaningful correlation or comparative questions as follow-ups. Descriptive results can also be effectively represented spatially in maps.

We should note here that some field researchers *do* manipulate conditions and create control and experimental groups. Field ecologists, for example, will occasionally burn a portion of a prairie and compare some aspects of this altered landscape with another section of prairie left in its natural state. In another example, scientists in Rhinelander, Wisconsin are studying the effects of carbon dioxide and ozone on trees using a type of "controlled experiment" in the field. On a massive plot of forested area, dozens of 30-foot high vertical tubes surround different 30-yard circles of trees. The trees encircled by these tubes are being exposed to carbon dioxide and ozone while nearby trees in this forest are experiencing "normal" conditions. Scientists hope this extravagant experiment will help them understand what effects elevated carbon dioxide levels in the future will have on trees (Karnosky et al., 2005).

Despite these exceptions, the point of this paper is that much of the science being practiced today is *not* characterized by such randomized and manipulated control group experiments, however most school science and high-stakes tests recognize *only* this paradigm of investigation.

To demonstrate the broader and more authentic range of inquiries scientists pursue, Table 1 shows the different types of investigative questions that guide each type of field investigation. (See also Kelsey and Steel (2001) for an elaborated list of investigative questions). As the standards (NRC, 1996) state, an essential feature of inquiry is to "ask a question about objects, organisms, and events in the environment" (p. 122).

K-12 Student Involvement in Field Investigations

Studies and program descriptions of field investigations typically emphasize how experiences outdoors in school yards, estuaries, parks, and public lands have impacted K-12 students' ecological content knowledge, attitudes about the natural environment, appreciation

Table 1. Types of Research Questions which Guide Field Investigators

Question Types	Sample Question Prompts
Comparative Questions	• Is there a difference in ______ between group (or condition) #1 and group (or condition) #2? • Is there a difference in _____ between different locations? • Is there a difference in _____ between two different times? • How does _____ change over a given area or distance? [How does pH change as you move over a 10-mile length of a stream?]
Correlative Questions	• What is the relationship between variable #1 ______, and variable #2 _______? • Does ____ go up when _____ goes down? • How does ______ change as ______ changes?
Descriptive Questions	• How many ______ are there in a given area? • How frequently does _______ happen in a given time period? • What is the [temperature, speed, height, mass, density, force, distance, pH, dissolved oxygen, light intensity, depth, etc.] of _______?

for a particular plant or animal species or habitat, and motivation (Brune, 2002; Cronin-Jones, 2000; Milton & Cleveland, 1995; Schnittka, 2006; Stivers, 2002; Wee, Fast, Shepardson, Harbor, & Boone, 2004; Woods, 2003), or increased student achievement (Lieberman and Hoody, 1998), or describe how teachers view the educational benefits of and barriers to using different types of environments as learning settings (Kent & Gilbertson, 1997; Simmons, 1998); however, they rarely articulate the features of inquiry involved in field investigation.

Below we describe two research programs that are collaborations between natural resource agency scientists and school age learners; one focuses on the study of short-horned lizards, the other on cougars. The examples demonstrate how each type of field investigation is used to examine different types of questions about the natural environment. Descriptive field investigations involve describing parts of a natural system. Comparative field investigations are the most similar to controlled investigations because data is collected on different groups, or under different conditions, to make a comparison. Correlative field investigations involve measuring or observing two variables and searching or a pattern.

Short-horned Lizard Studies

Students at Waterville Elementary School in Washington State and local area farmers have worked together since 1999 to examine several aspects of short-horned lizard biology. (See http://www.fish.washington.edu/naturemapping/ and http://www.fish.washington.edu/naturemapping/waterville/menu.html for more information about nature mapping and the data collected about short-horned lizards.) Like scientists, students at Waterville Elementary are engaged in descriptive, comparative, and correlative studies.

Descriptive Studies: With guidance from Karen Dvornich, National Director for NatureMapping at the University of Washington, and Diane Petersen, a teacher at Waterville Elementary School, second graders have recorded and graphed food preferences for the local lizards, their habitat niches, and body characteristics such as length, weight, and color. Thus, students explore descriptive questions such as: "What do lizards eat?" and "Where are the lizards most common?" When fourth graders at the school wanted to know what the short-horned lizard did over the winter, a literature search and discussions with experts provided little data on hibernating lizards. The students then decided to build an enclosure in the schoolyard in an attempt to mimic conditions in the field. The students' work provided new descriptive insights into how the lizards behave during the change of seasons (Peterson, 2005).

Comparative Studies: Some fourth-graders were interested in learning about home range and daily and seasonal movements of the lizards. Local area farmers brought information about lizard sightings to the students, and the students then identified and marked these locations on maps. While this is another type of descriptive inquiry, the students are currently planning a comparative study, based on this descriptive information. They plan to fit a number of lizards with radio collars and will collect data comparing the amount of movement the lizards undertake during each of the four seasons. This comparative study grew out of earlier descriptive studies and is focused on the comparative question, "Is there a difference in lizard movement in different seasons?" (Here the comparison is a different condition, the time of year).

Correlative Studies: Another study being planned at Waterville Elementary includes correlating lizard abundance with temperature and rainfall data, using tools such as geographic information systems (GIS) and spreadsheets. Students' can investigate the correlative question, "What is the relationship between temperature and rainfall and lizard abundance?" Once several years of data are collected, students will begin to make predictions about lizard abundance based on weather forecast information.

Project CAT (Cougars and Teaching)

At Cle Elum Senior High School, students have been tracking cougar locations in a western Washington county. With the help of Gary Koehler from the Washington State Department of Fish and Wildlife, cougars have been tagged with a global positioning system (GPS) unit, which provides readings of 600 precise locations of each animal per year. (See http://www.fish.washington.edu/naturemapping/projects/cat and http://wdfw.wa.gov/science/articles/cougar/ for more information about nature mapping and Project CAT.) Like scientists, Cle Elem High School students engage in descriptive, comparative, and correlative studies.

Descriptive Studies: In an effort to answer the descriptive question, "Where do cougars go when their habitat gives way to a new housing development?" Dr. Koehler and students participate in capturing the cougars, marking them with ear tags, and collecting physical data that includes length, neck girth, chest girth, length and condition of canine teeth, and weight. They collect blood and tissue samples for disease analysis and DNA profiling, respectively. Students are also involved with radio-tracking animals from the air and from the ground. They plot coordinates of cougar locations on computer-generated maps of the study area, and use computer programs to calculate the space each cougar occupies annually and during each season. The location information allows scientists to study the home range of the animal throughout the year.

Comparative and Correlative Studies: At Cle Elem High School students have planned a future study of the winter population distribution of deer and elk. They will set up study zones within different forest types in an effort to answer the comparative question, "What is the relationship between forest stand characteristics and deer/elk populations?" Students will be involved in classifying forest stands and measuring stand characteristics such as slope and canopy cover. Wintertime deer and elk track data will be collected and then used to compare between forest stands. Students will also be introduced to simple statistical procedures to investigate correlations between the numbers of animal tracks present and the characteristics of each forest site.

By examining the work of scientists and K-12 students engaged in research in natural settings we developed a comparative model of field investigations.

Methodology: Building a Comparative Model

Because of the narrow interpretation of inquiry used in most classrooms and to develop many state assessments in science, a panel of experts was convened in Washington State in 2004 to create an investigation template to help teachers conceptualize and assess *field studies* by students. This panel included scientists, learning sciences specialists, assessment specialists, master teachers, and members of the Office of the Superintendent of Instruction (Appendix A). The template was intended to also direct the development of field investigation items on the state science assessments. It was one of several documents produced that helped articulate new visions of inquiry (Office of Superintendent of Public Instruction, 2005).

In creating the template, we began with a descriptive study, documenting the inquiry processes used by natural resource agency and university scientists engaged with field investigation. The panel of experts provided a peer review process to describe and analyze the varied nature of field investigations. We then documented the work of two school sites engaged in field investigations. From these descriptions (provided by scientists and students doing research in the natural environment) we identified three types of field investigations (descriptive, comparative, and correlative) and compared each to the essential features of inquiry; thus, we developed a comparative model for field investigation.

A Comparative Model for Field Investigations

Clearly much of science, and in particular field investigation, calls for ways of coordinating data and the development of models that go beyond manipulated control group/experimental group designs. Table 2 outlines the contrasts and similarities between the designs of descriptive, comparative, and correlative field investigations and relates these to the "essential features of inquiry" (Martin-Hansen, 2002; NRC, 2000). The key differences relate to the framing of the investigative question, identification of variables, ways in which the data is re-represented, and the form of the conclusions.

Table 2. Similarities and differences among Research Designs of Field Investigation

	Descriptive	Comparative	Correlative
Formulate Investigative Questions	Question to Guide Observation	Prediction/Hypothesis	Hypothesis
	How many? How frequently?	Is there a difference between groups or condition?	Is there a positive or negative relationship between two variables?
Identify Setting within a System	Identify geographic scale of investigation (e.g., riparian corridor or Cedar River Watershed) Identify time frame of the investigation (e.g., season, hour, day, month, year)		
Identify Variables of Internet	Choose measurable or observable variables	Choose one focus variable to be measured/observed in at least two different locations, times, or populations	Choose two continuous variables to be measured together and tested for a relationship
Collect Data (Systematize how, when, and where data will be collected)	Multiple measurements over time or location in order to improve system representation (model) Individual measurement is repeated if necessary to improve data accuracy Record and organize data into tables(s) or other forms		
		Describe how sampling was consistent for the two or more locations, times or organisms (controls) Identify and account for extraneous factors that might have an effect on the focal variable(s).	
Analyze Data	Means, medians, ranges, percentages, calculated when appropriate Organize results in graphic and/or written forms and maps using statistics when appropriate		
	Typical representations of the data to build a descriptive model:Charts, line plots, bar graphs, maps		Typical representations of the data to demonstrate correlations upon which models are developed: scatter plots, r-values
Use Evidence to Support an Explanation	Use data to support an explanation. Limit conclusion to the specific study site. Compare data to standards. Identify factors that may have affected the validity of the findings. Compare data to other similar systems/models. Discuss how results help answer the system's question and add to our understanding of the model/system. Make recommendations for future research (new questions, hypotheses or procedures) and suggest applications.		
	Does the data summary answer the investigation question?	Does the evidence support the hypothesis?	

The comparative model demonstrates that all three types of field investigations involve essential features of scientific inquiry, such as "identify[ing] questions that can be answered through scientific investigations," planning a systematic approach to data collection, and "develop[ing] descriptions, explanations, predictions, and models using evidence" (NRC, 1996, p. 145).

The comparative model also highlights important differences. Each type of field investigation is guided by different types of investigative questions. They evolve from descriptive to comparative, to questions about relationships, or correlative questions. In addition, each type of field investigation focuses on different variables. For comparative and correlative studies it is important to consider how sampling was consistent across two or more conditions and to identify and account for extraneous factors that might have an effect on the focal variable(s). Data collected in descriptive and comparative studies is typically represented in a similar manner (e.g., charts, line plots, bar graphs and maps). In contrast, data collected in correlative studies is typically represented as scatter plots or r-values. In comparative and correlative studies it is important to relate evidence to a stated hypothesis, whereas in descriptive studies a summary of the data, often a map or model of the system, is used to answer a descriptive question.

This model also demonstrates a sequential relationship between the three types of field investigations (descriptive studies can lead to comparative studies, which can lead to correlative studies) and that comparative studies are a bridge between descriptive and correlation studies (and share common attributes with each of them). We have targeted comparative studies as an important emphasis for school instruction because of the similarities they share with descriptive and correlative studies and their similarity to controlled investigations where one variable is changed to create a controlled comparison. We should note that the panel decided that correlative studies would be completed only by 10th graders, due to the fact that students have to understand some rudiments of the statistical basis for correlations in order to draw conclusions from such studies, and must understand the difference between continuous and categorical variables.

Conclusions

By building a comparative model of three different types of field investigation we hope to demonstrate that there is more to science than cause-effect research and that scientific inquiry is not limited to hypothesis testing. We are not asserting that field investigations are separate from inquiry, but instead that scientific inquiry takes many forms and that all scientific investigations, including field investigations, are concerned with validity and consistency and are designed to answer an investigative question through the systematic collection of evidence and the communication of results. As the standards (AAAS, 1993) highlight, inquiry "is far more flexible than the rigid sequence of steps commonly depicted in textbooks as 'the scientific method.' It is much more than just 'doing experiments,' and it is not confined to laboratories" (p. 9).

Through building this model we are now more intentional in our work with students, teachers, and scientists because we have clarified and agreed upon a common language, or framework, for describing three different types of field investigations. Our state standards now include field investigation as one form of scientific inquiry (Office of Superintendent of Public Instruction, 2005). Although some caution against linking environmental education to conventional standards, or supporting academic standards and testing (Gruenewald, 2004), we created a rubric to guide the development of state science assessment items about field investigation. In our work with teachers we focus on comparing and contrasting the different types of investigative questions that guide field studies. In addition, because we identified differences in the ways data is re-represented, we are now more intentional in engaging teaches to create, analyze, and critique representations of data. A surprising outcome of our work is that natural resource agency scientists cite how this model has helped them to describe the systematic nature of the field investigations they conduct.

While much thought has gone into the development of this comparative model, the model does not represent "finished thinking." Rather, this is an initial attempt to introduce more authentic forms of inquiry into the science standards and into the lives of students. The effort is long overdue. Not only are these forms of investigation more representative of the types of science being done today, and help students learn that "scientists conduct investigations for a wide variety of reasons" (NRC, 1996, p. 176), they are also more engaging for young learners. We invite critique, refinement, and elaboration of this comparative model by others dedicated to a vision of school science that emphasizes many different forms of scientific inquiry.

References

Alters, B. (1997). Whose nature of science? *Journal of Research in Science Teaching, 34*(1), 39-55.

American Association for the Advancement of Science. (1993). *Science for all Americans*. New York: Oxford University Press.

Anderson, C. R., & Lindzey, F. G. (2003). Estimating cougar predation rates from GPS location clusters. *Journal of Wildlife Management, 67*(2), 307-316.

Brune, J. (2002). Take it outside! *Science and Children, 39*(7), 29-33.

Cronin-Jones, L. L. (2000). The effectiveness of schoolyards as sites for elementary science instruction. *School Science and Mathematics, 100*(4), 203-211.

Feyerabend, P. (1993). *Against method* (3rd ed.). London: Verso.

Gillespie, I. G., & Allen, E. B. (2004). Fire and competition in a southern California grassland: Impacts on the rare forb Erodium macrophyllum. *Journal of Applied Ecology, 41*(4), 643-652.

Griffin, L. (1892). The laboratory in school. *School and College, 1*, 477.

Goodin, D. G., Gao, J., & Hutchinson, J. M. S. (2004). Seasonal, topographic and burn frequency effects on biophysical/spectral reflectance relationships in tallgrass prairie. *International Journal of Remote Sensing, 25*(23), 5429-5445.

Gruenewald, D. A. (2004). A Foucauldian analysis of environmental education: Toward the socioecological challenge of the Earth Charter. *Curriculum Inquiry, 34*(1), 71-107.

Harwood, W. (2004). An activity model for scientific inquiry. *The Science Teacher, 71*(1), 44-46.

Karnosky, D. F., Pregitzer, K. S., Zak, D. R., Kubiske, M. E., Hendrey, G. R., Weinstein, D., Nosal, M., & Percy, K.E. (2005). Scaling ozone responses of forest trees to the ecosystem level in a changing climate. *Plant, Cell and Environment, 28*(8), 965-981.

Kelsey, K., & Steel, A. (2001). *The truth about science: A curriculum for developing young scientists*. Arlington, VA: National Science Teachers Association.

Kent, M. & Gilbertson, D. D. (1997). Fieldwork in geography teaching: A critical review of the literature and approaches. *Journal of Geography in Higher Education, 21*(3), 313-332.

Knorr-Cetina, K. (1999). *Epistemic cultures: How sciences make knowledge*. Cambridge, MA: Harvard University Press.

Latour, B. (1999). *Pandora's hope: Essays on the reality of science studies*. Cambridge, MA: Harvard University Press.

Latour, B. (1987). *Science in action*. Cambridge, MA: Harvard University Press.

Lieberman, G., & Hoody, L. (1998). *Closing the achievement gap: Using the environment as an integrated context for learning*. Poway, CA: Science Wizards.

Martin-Hansen, L. (2002). Defining inquiry: Exploring the many types of inquiry in the science classroom. *The Science Teacher, 69*(2), 34-37.

McGinn, M., & Roth, W.-M. (1999). Preparing students for competent scientific practice: Implications of recent research in science and technology studies. *Educational Researcher, 28*(3), 14-24.

Milton, B., & Cleveland, E. (1995). Changing perceptions of nature, self and others: A report on a park-school program. *Journal of Environmental Education, 26*(3), 32-39.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.

National Science Teachers Association. (1995). *Scope, sequence, and coordination of secondary school science* (Vol. II). Washington, DC: Author.

Office of Superintendent of Public Instruction. (2005). Appendix E: Scientific field investigations. In *Science K-10 grade level expectations: A new level of specificity* [On-line]. Available: http://www.k12.wa.us/curriculumInstruct/science/pubdocs/ScienceEALR-GLE.pdf.

Owens, L. (1985). Pure and sound government: Laboratories, playing fields, and gymnasia in the nineteenth century search for order. *Isis, 76*, 183-185.

Peterson, D. (2005, April/May). Leapin' lizards [18 paragraphs]. *Edutopia* [On-line serial]. Available: http://www.edutopia.org/magazine/ed1article.php?id=Art_1251&issue=apr_05

Pinho, P., Augusto, S., Branquinho, C., Bio, A., Pereira, M. J., Soares, A., & Catarino, F. (2004). Mapping lichen diversity as a first step for air quality assessment. *Journal of Atmospheric Chemistry, 49*, 377-389.

Rudolph, J. (2004). *Epistemology for the masses: John Dewey and the scientific method in American schools*. Unpublished manuscript, University of Wisconsin.

Schnittka, C. (2006). Learning lessons from estuaries. *The Science Teacher, 73*(1), 31-35.

Simmons, D. (1998). Using natural settings for environmental education: Perceived benefits and barriers. *Journal of Environmental Education, 29*(3), 23-31.

Stivers, L. (2002). Discovering trees: Not just a walk in the park! *Science and Children, 39*(7), 38-41.

Tolley, K. (2003). *The science education of American girls*. New York: RoutledgeFalmer Press.

Wee, B., Fast, J., Sheparson, D., Harbor, J., & Boone, W. (2004). Students' perceptions of environmental-based inquiry experiences. *School Science and Mathematics, 104*(3), 112-118.

White, R. (2003). Changing the script for science teaching. In R. Cross (Ed.), *A vision for science education: Responding to the work of Peter Fensham* (pp. 170-183). London: RoutledgeFalmer.

Woods, H. R. (2003, Fall). Early birding. *California Wild*, 43-45.

Appendix A

Panel that developed Field Investigation Comparative Model:

Dr. Jonas Cox, Gonzaga University, Teacher Education

Dr. Mark Windschitl, University of Washington, School of Education

Dr. Timothy Nyerges, University of Washington, Department of Geography

Dr. Edoh Amiran, Western Washington University, Math Department

Dr. Gary Koehler, Field Biologist, Washington Department of Fish and Wildlife

Dr. Martha Kurtz, Central Washington University, Science Education

Science Teachers, Tahoma, West Valley (Spokane) and Tumwater School Districts.

The following individuals assisted the panel:

Dr. Catherine Taylor, University of Washington, Educational Psychology

Roy Beven, Science Assessment Director, OSPI

Eric Wuersten, Science Curriculum Director, OSPI

Pat Otto, Consultant, Pacific Education Institute & OSPI Science Assessment

Dr. Margaret Tudor, Co-Executive Director, Pacific Education Institute

Karen Dvornich, Director of NatureMapping, Cooperative Fish and Wildlife Research Unit, University of Washington.

Kayleen Pritchard, Consultant, Pacific Education Institute

Author's Note

Correspondence concerning this article should be addressed to Margaret Tudor, Pacific Education Institute, Market Place Office Building, 724 Columbia St. NW, Suite 250, Olympia, WA 98501. Electronic mail may be sent via Internet to mtudor@wfpa.org.