Science & Education **11:** 55–67, 2002.

The Use and Impact of Explicit Instruction about the Nature of Science and Science Inquiry in an Elementary Science Methods Course

JULIE GESS-NEWSOME
Northern Arizona University, Science & Mathematics Learning Center, Box 5697, Flagstaff, AZ 86011-5697, USA; E-mail: julie.gess-newsome@nau.edu

Abstract. Teachers' understanding of the nature of science (NOS) and science inquiry (SI) can be linked to the use of the teaching methods advocated by the current science education reforms. The purpose of this study was to describe and evaluate an elementary science methods course in which the NOS and SI are embedded and explicitly taught. As a result of the course, incoming conceptions of science as primarily a body of knowledge changed to a more appropriate, blended view of science as a body of knowledge generated through the active application of scientific inquiry.

Why Should Elementary Teachers Know About the Nature of Science and Science Inquiry?

Lederman (1998) stated that providing teachers with a functional understanding of the nature of science (NOS) and scientific inquiry (SI) is "prerequisite to any hope of achieving the vision of science teaching and learning specified in the various reform efforts" (p. 2), such as *Project 2061* (AAAS, 1989, 1993) and the *National Science Education Standards* (NRC, 1996). The NOS is defined as the epistemological underpinnings of science and includes characteristics such as empirically-based, tentative, subjective, creative, unified, and cultural and socially embedded. Individuals who understand the NOS can recognize the functions of and distinguish among observations, inferences, scientific facts, laws, and theories. SI "extends beyond the mere development of process skills … [and] refers to the combining of these processes with scientific knowledge, scientific reasoning, and critical thinking to develop scientific knowledge" (p. 5). Scientific processes, such as observation, prediction, and classification, are applied in a flexible manner during science problem solving and knowledge generation.

Three approaches to teaching the NOS and SI have been described and evaluated (Lederman, 1992, 1998). The implicit approach assumes that participation in science will result in an understanding of the NOS and SI. Research has shown this model to be ineffective. Research on the historic approach, in which the NOS is taught through the history of science, has provided inconclusive evidence as to its effectiveness. The explicit approach is advocated by Lederman (1998) and has evidential support for its effectiveness. Not to be confused with direct instruction, in the explicit approach the NOS and SI are used as a context for the generation and learning of scientific knowledge, permeating the curriculum. Purposeful planning, integration, and discussion of the interplay of the NOS and SI with scientific knowledge is necessary. Explicit instruction models, discusses, and distinguishes between the skills of SI (the "how" of doing science), the cognitive outcomes of SI (the "why" of doing science), and the pedagogical applications of SI (the how and why of inquiry-based science instruction).

While past research has shown that teachers' understanding of NOS does not directly translate into classroom practice, it is also obvious that teachers cannot present or assess information they do not possess (Lederman, 1992, 1998). Without such a background, teachers carry positivistic views of their discipline, teach only the knowledge aspects of science, emphasize vocabulary rather than balance knowledge claims with knowledge generation and evaluation, and present science as *the* method of understanding the world (Gess-Newsome 1999). Additional classroom consequences may include a decreased emphasis on inquiry-oriented and problem solving teaching methods that positively impact students' conceptions of NOS (Gess-Newsome 1999; Lederman 1992).

Science methods courses have been found to be an effective forum for positively impacting preservice teachers' conceptions of science content, the NOS, SI, and appropriate pedagogical practices in science. The purpose of this study is to describe an elementary science methods class in which the NOS and SI were used as the framework for instruction, and to evaluate the impact of such instruction on preservice teachers' views of science. Specifically, views pertaining to the definition of science (science as content, process, or a blending of the two) were investigated.

What Does Explicit Instruction in the Nature of Science and Science Inquiry Look Like in an Elementary Science Methods Course?

The elementary science methods course met for 2 hours, twice a week, for 10 weeks. The course was specifically designed to simultaneously meet three goals: to help students develop understandings about science content, the NOS, and SI; to provide students with experiences in inquiry-based science instruction; and to assist students in the design and implementation of inquiry-based science instruction. The first 6 weeks of the course immersed the students in inquiry-based science lessons similar to those advocated for use in the public schools (see Table I). The lessons were designed to challenge incoming beliefs about how science should be taught, to blend the presentation of science content and processes, and to teach specific methods of science instruction. The last four weeks of the course were dominated by student presentations of unit plans designed for use in the public schools; verbal debriefing on the nature, sequencing, and effectiveness of the unit; and a discussion of a science teaching issue or method. Course assignments included reflective

Table I. Elementary science methods course outline

Week	Session 1 topics	Session 2 topics
1	Introductions, journal 1, Oobleck	Science teaching goals, professional associations
2	Journal 2, Swingers	Nature of scientific inquiry and card sort
3	Journal 3, types of inquiry, questioning strategies, demonstrations	Pure vs guided discovery, planning considerations
4	Journal 4, experiments, learning centers	Cooperative learning
5	Journal 5, student interviews	Technology in elementary science teaching
6	Problem solving and process skills	Equity issues in science teaching
7	Unit 1 presentation, promoting science interests in the classroom	Unit 2 presentation, integration of science across the curriculum
8	Unit 3 presentation, lab safety	Unit 4 presentation, science assessments
9	Unit 5 presentation, science equipment	Unit 6 presentation, Science fairs
10	Unit 7 presentation, outdoor classrooms	Unit 8 presentation, evaluations, journal 10

journal writings, student interviews, the writing and teaching of two inquiry-based science lessons in an elementary classroom, the development and presentation of a science unit, and the organization of a science teaching resource file.

The lessons described in this paper were selected for their ability to illustrate the intertwining purposes of teaching science content, the NOS and SI, and science pedagogy. While the selection and use of any lesson from the course would support the aforementioned purposes, many of the lessons were also designed to teach an instructional model or strategy, illustrate decisions related to classroom management, or highlight equity issues in science education. To decrease complexity, only those aspects of the lesson related to the NOS and SI are described. Discussions of other lesson emphases, such as equity, can be found elsewhere (Gess-Newsome & Southerland 2000; Southerland & Gess-Newsome 1999).

OOBLECK

Oobleck (Sneider 1985) is a four session sequence developed by Lawrence Hall of Science as part of their Greater Explorations in Math and Science (GEMS) curriculum. The lesson sequence allows students to actively explore a thick mixture of cornstarch, water, and green food coloring. Only session 1 was used in the methods course.

Following the completion of Journal 1 and group introductions, the Oobleck lesson was introduced by displaying a container of a mysterious substance purportedly obtained from outer space. The students' task was to describe the substance as completely as possible. Prior to the distribution of materials, a piece of chalk was used as a practice object to elicit descriptions. Descriptions, based on student observations and instructor prompts ("What would happen if I drop the chalk?") were listed on the board. After 5–8 descriptors were listed, the term "property" was introduced as a heading for the list and the students were challenged to form a working definition for the term. Oobleck was then distributed to groups of 4–5 students at newsprint covered tables. During group work, the instructor circulated and asked questions based on the prompt: "Why does the substance sometimes act like a liquid and sometimes act like a solid?" Additional equipment (i.e., water, droppers, spoons) was offered to test ideas that were being formulated about the substance. Following 10 minutes of observation and testing, each group was given a large piece of paper on which to record their observations. Observations were posted on the wall, described, and analyzed. Lesson summary and debriefing included the definition a property; the nature of empirical evidence in science; the distinction between observation, inference, and fact; the process of forming and testing hypotheses; the difference between a testable and non-testable inference (a testable inference was defined as a hypothesis); the use of scientific processes as a means of answering questions and generating explanations; and the similarities and differences between this lesson and those to which the preservice teachers had been previously exposed.

SWINGERS

The Swingers lesson (Lawrence Hall of Science 1981) was adapted from the SAVI/SELPH program sponsored by the Center of Multisensory Learning. The lesson teaches about pendulums, the role of variables and controlled experiments in determining causal explanations, and the relationship between the length of a pendulum arm and its period. The preservice teachers were asked to attend to the lesson at multiple levels: as students participating to learn the content about pendulums, as students developing a sense of the NOS and SI (i.e., the design and rationale behind a controlled experiment), and as a teacher considering pedagogical issues (i.e., content development to facilitate student learning, lesson transitions, and material distribution).

The lesson was introduced by showing the preservice teachers a swinger – a 32 cm string with a loop on each end. The top loop was suspended from a pencil that was taped perpendicularly to a desk. The bottom loop had an attached paper clip, bent open to hold a metal washer. After familiarizing the student with the parts of a swinger (arm, mass, pivot point) and drawing the connections between it and other pendulums, the students were asked to determine the number of cycles a swinger can complete in 15 seconds. With student materials in hand, the instructor started the countdown toward timing the number of swings in 15 seconds. Invariably in response to "any questions before we proceed?", the students will ask to define a swing and the details of the release procedure. These questions were used to discuss operational definitions and their role in science. With these definitions in place, the students determined the period of their swinger. Despite similarities in construction, differences in period were noted and introduced the need for repeated trials to establish measurement standards, issues related to experimental error and introduced bias, and efforts to reduce both.

After standardizing procedures and establishing the period of the swinger, the students were asked to suggest ways to alter the period. Variations in release point, mass, and length of arm were offered and recorded on a data collection grid. Mechanisms for creating a "fair" test of each variable were discussed and used to define the terms: variable, control, and controlled experiment. The purpose of averaging trials was restated and the variables were systematically tested. Prior to each test, the students were asked to discuss with their partner, record in writing, and verbally offer a prediction as to the outcome of the upcoming experiment. This process was discussed in terms of differentiating and synthesizing the use of such terms as guess, prediction, inference, and hypothesis, and the role of prediction in both science and science pedagogy. Specifically, the students were challenged to recognize that conducting a test without a reasoned prior explanation prevented the recognition of pre-conceptions and their potential challenge by both the students and the teacher.

The final variable tested, length of pendulum arm, resulted in the first variation in period. In order to collect materials and establish a basis for examining the data, the students hung the swingers along a number line, representing the number of swings in 15 seconds. Based on the graphical display, the students were asked to state the apparent relationship (the longer the string, the fewer the swings). The nature of this relationship was compared to definitions derived for observation and fact. When it was recognized that more information was contained in the relationship than in a simple fact, though no explanation was provided, definitions and examples of laws and theories were introduced.

To complete the lesson debriefing, the preservice teachers were offered a brief overview of a verification model of the same lesson: a definition of a pendulum and a statement of the relationship between arm length and period was provided. This information was followed by lab outline with preset instructions to test the impact of variations in mass, release point, and length of arm on the pendulum period (even though the answer was previously stated). The lesson concluded with a discussion of the learning outcomes, ownership of knowledge, and time efficiency resulting from the two teaching methods.

NATURE OF SCIENCE CARD SORT

The Oobleck and Swingers lessons introduced the preservice teachers to a number of concepts related to NOS and SI. A card sort of the terms was designed to foster the explicit exploration of the understanding of the NOS and SI through personal and social discourse. In groups of 4–5, the students were given the following terms on individual cards: fact, theory, experiment, observation, trials, hypothesis, law, variable. With the encouragement to add additional terms and arrows, lines, or other graphic aids to enhance their explanation, the students were asked to organize the terms on a large sheet of paper in a manner that reflected the groups' agreed upon understandings. Final graphics were presented to the class and explained by a group member.

To summarize the lesson and provide a platform for later learning and class activities, the students were introduced to the interrelated aspects of the nature and definition of science: science as a body of knowledge, a process, and a way of knowing. This definition of science was discussed and related to class activities as well as the students' understandings of science, the NOS, and SI. The characteristics of the NOS (i.e., amoral, creative, tentative, parsimonious, testable, and unified) were then introduced and discussed (Rubba & Anderson, 1978).

To reinforce the idea that humans are sense making creatures in a cultural and historical context, images that challenge sense making ability were introduced, such as M.C. Escher prints and images of gestalt perceptional switches (i.e., duck/rabbit, old lady/young maid; see Lederman & Abd-El-Khalick 1998) and the reading of "The Procedure" (Bransford 1979), a short statement that begins with: "The procedure is quite simple. First arrange things into different groups". The story line continues, but the nature of the "things" remains open to reader interpretation. Two points were emphasized from these activities: that humans are uncomfortable in situations where they cannot make sense of the world and will invent explanations to ease this discomfort; and that competing interpretations are naturally compared against available evidence until a preferred explanation is selected. Once selected, it is unlikely that an explanation will be easily rejected, even in the face of contradictory evidence. The relationship of these points to the presence and tenacity of student misconceptions, as well as to the nature of explanations and theories in science, concluded the lesson.

ADDITIONAL COURSE ACTIVITIES

Space prevents the detailed description of other lessons. In short, instruction in specific teaching methodologies followed a similar pattern: students were introduced to a strategy and participated in a science lesson. Each lesson was debriefed as to the science content, the NOS and SI, the instructional model, issues related to classroom implementation, and the impact of the model on student learning. The student interview assignment was used to collect and analyze data from elementary students and relate the findings to the nature of learning theories and instructional design. Lesson and unit plans continued the reinforcement of integrating science content and the NOS and SI by requiring students to outline the lesson content, whether it be conceptual knowledge, process skills, or both.

How do Elementary Preservice Teachers' Conceptions of Science Change as a Result of Explicit Instruction in the Nature of Science and Science Inquiry

PROGRAM CONTEXT AND COURSE PARTICIPANTS

This science methods course was embedded within a 3-quarter, senior year, cohort-based elementary certification program. Prior to program admission, the students completed two science content courses and numerous content and education prerequisites. The first quarter of the program consisted of five courses: science methods, social studies methods, aesthetics methods, classroom management, and a seminar. The second semester consisted of methods courses in reading, language arts, and mathematics, and a seminar. Students were placed in an elementary classroom for the duration of the program and observed and taught in that classroom two full days each week during the first two quarters. Full time student teaching occurred during the third quarter.

There were 30 students in the cohort from which this data was drawn. Demographic features include 28 females and 2 males, 29 Caucasians and 1 African American. Ages ranged from 21 to 44, with a median age of 25, and the average GPA was 3.4 at program admission.

DATA COLLECTION AND ANALYSIS

The purpose of this study was to evaluate the impact of explicit NOS and SI instruction on student's conceptions of the definition of science. Journal questions were assigned for each of the first five weeks of the course to focus and elicit student conceptions about science teaching; the definition, nature and organization of science; goals of science instruction; role of the teacher; and gender and equity issues in science teaching.

A final journal entry requested the students to create a philosophy of science teaching. The students were asked to answer the questions truthfully, with grades based on answer thoughtfulness versus content.

Journal responses from weeks 1, 4, and 10 (identified numerically by week and question number) directly addressed issues related to the NOS and SI and were used as data sources for this study:

Questions 1-2 and 4-1: Define science.

Questions 1-4 and 10-2: What topics, ideas, or actions make up science? What would a diagram of these components look like? Write a short description (2 or 3 sentences) explaining what you have portrayed and why.

The author's past experience with teaching this course and eliciting preservice teachers' conceptions of the NOS have revealed the tendency to define science in terms of disciplinary fields (i.e., biology, chemistry, geology) and/or specific content topics (i.e., plants, animals, rocks, weather) (Gess-Newsome & Lederman 1993; Lederman et al. 1994). Therefore, changes in views of science from a product-based conception to a blend of product and process, or a process-based conception were sought.

Following data collection, the preservice teachers' papers were given a numerical student code and their conceptions of science were placed into one of five categories. *Product* views defined science as a body of knowledge. *Process* views described science as a method of gaining knowledge. *Blended* views contained aspects of both the process and product orientations. Answers that were vague and therefore defied categorization were listed as *Unclear*, and missing data were listed in the *No answer* category.

Starting from these initial categorical descriptions, operational definitions of the categories based on student responses were derived by the author and are listed in Tables II and III along with data exemplars. Answer categories were then assigned by the author and verified by another science education researcher and methods instructor. An initial agreement level of 84% was achieved. Following category clarification, a second data sort resulted in 92% agreement. Category disagreements were mitigated by discussion and consensus. Responses categories are recorded by student code and by question in Table IV, allowing for the identification of changes in individual students.

RESULTS AND DISCUSSION

Often parroting definitions of science that may have been memorized in school, 14 of the incoming definitions of science were unclear for the purposes of categorization. Of those answers that could be categorized, 9 were listed as product, 2 as blended, and 4 as process. These numbers can be compared to the categorizations of the second question, with 17 listed as product, 5 as blended, 5 as process, and 2 as unclear. While it is tempting to interpret the categories for question 1-2 from the corresponding categorization of question 1-4, an inspection of the consistency of answers across question categories does not seem to support such an assumption. Therefore, upon course entry, the students were categorized as primarily having unclear or product oriented views of science.

The inconsistency in student answers across questions within a single journal entry it intriguing. For instance, students 12, 14 and 22 had answers to question 1-2 classified as process, while answers to question 1-4 were classified as product. A variety of explanations may exist. First, the student may be unclear as to her views of science, thus answering questions with low reliability. Second, with unclear initial conceptions of science, each questions may be acting as a stimulus to her thinking, a finding consistent with those of Gess-Newsome & Lederman (1993). Third, the questions may be tapping into different cognitive conceptions about science, hence triggering different responses.

There was a general trend for students to migrate from product to blended or process-based conceptions of science over the duration of the course. The most significant movement of student conceptions was seen between weeks 1 and 4,

Table II. Categorization of written descriptions of science

Category	Data exemplars, Questions 1-2 and 4-1
Product: Science defined as topics to be learned. The knowledge is inert.	"Understanding why things really happen the way they do". (1-2, 2) "Science encompasses the physical aspects of our lives. The earth, solar system, plants, animals, air, water, our bodies, etc.". (4-1, 16) "Science is a knowledge of nature and the physical [world]". (4-1, 28)
Process: Science described as a process of gaining knowledge or applying process skills. The knowledge is active.	"Science is testing ideas, comparing results to ideas, gathering and organizing information". (1-2, 14) "It is a process of answering questions about our world (and universe). It is a process of discovery and a way of making sense of our world". (4-1, 1) "Science is the process of discovering how and why the world works in certain ways". (4-1, 3)
Blended: Science described as a body of knowledge produced through the application of processes.	"Science . . . is understanding the world and environment around us. Trying to understand by experimenting, observing, collecting information, etc. I also think that science is trying to understand the "why" behind things". (4-1, 2) "Science is a process and the accompanying knowledge that is gained from experiencing processes. It is defined as 'the observation, identification, description, experimental investigation, and theoretical explanation of natural phenomenon'. But, more than this, it is being able to use natural laws to make sense of our environment and question what we see around us". (4-1, 18)
Unclear: Vague answer defied categorization.	"Discovering what the world around us is made of and what makes it function". (1-2, 3) "Study of the physical world. How things work and why". (1-2, 9) "A study of our world and universe. Starting with atoms all the way up to universe". (1-2, 28)

the period of most intensive instruction in NOS and SI. A qualitative analysis of student answers showed an increase in the use of terms and concepts introduced in class in question 4-1. For example, descriptions of science as relevant, socially and culturally constructed, and important for its fostering of problem solving and critical thinking skills, appeared in student answers, such as the following:

> Science is a body of knowledge. Science often answers questions of how and why. Science is a learning process which helps determine "truth". The process

Table III. Categorization of diagrams of science

Category	Data exemplars, questions 1-4 and 10-2
Product: Science is defined as body of knowledge, often portrayed as a list of science topics. Knowledge is inert.	Science / | \\ Environment You World | | | Cleanliness Body Chemistry | functions | How it affects Physics who we are | Biology "Science is a part of everyday life. It is difficult to diagram all that science is. These three main points can be divided into sub-points, which all have bearing on the world". (1-4, 26)
Process: Science is described as a process of actively gaining knowledge, often including terms or statements related to applying process skills.	"1-Seeing a problem or something that interests you and investigating it. 2-Drawing a hypothesis. 3-Performing experiments. 4-Drawing a conclusion. Science is a subject that demands action from the learner. I diagramed the actions that make up science in this way because first the learner has to be able to pick an item that they want to investigate or learn about. This comes from reading the science book. After learning some basic information about the topic, they draw up a hypothesis, experiment, and form a conclusion. This is how you completely learn. You don't get this from just reading a book", (1-4, 7) "Identifying → Experimenting → Hypothesizing → Problem Solving → Conclusion I believe that these are the components of science because first you have to identify a problem or identify something that interests you. Then you experiment with that problem to see how it works. After experimenting, you can make a hypothesis. More experimentation and problem solving comes. Finally, a conclusion can be made. This is science because it allows you to understand and explore phenomena of the world". (10-2, 7)
Blended: Science is described as a body of knowledge produced through the application of processes.	"Subjects (animals, earth, gravity, etc.) → make a guess, decide what you want to learn → experiment, research → draw conclusions. Science is made up of chemistry, biology, botany, & astronomy. It involves experimentation and making hypotheses and discovering answers. In science, you choose what you want to study, experiment and research to get information, and from that information draw conclusions". (1-4, 24) "I see science as a tree with three main branches: earth science, physical science, and life science. Coming off those main branches are sub-branches with an almost limitless amount of branches coming off those. To me, anything can become a science lesson: the topic range is limitless. Covering this myriad of branches are a smattering of leaves. These leaves are things like creativity, exploration, discovery, predicting, questioning, etc., and they cover, overlay, the whole tree". (10-2, 23)
Unclear: Defied categorization.	"This is difficult. Science encompasses so many areas. I guess it would be a tree diagram". (1-4, 1)

of scientific learning provides a physical way of knowing which aids in developing personal belief systems based on empirical evidence. Science helps us as individuals construct reality through observations and tests. The discovery of answers through scientific study is done differently in other countries and continents than it is in America, sometimes giving a different view to results. (4-1, 12)

Changes in conceptions were sometimes noted and explained by the students along with their journal answers. For instance, student 14 notes: "I previously defined science through what was being taught. My new com-

Table IV. Categorization of science descriptions by student code

Question	Product	Blended	Process	Unclear	NA
1-2	2, 5, 11, 16,17, 20, 24, 26, 30	15, 19	12, 14, 22, 25	1, 3, 4, 6, 7, 8, 9, 10, 18, 21, 23, 27, 28, 29	13
1-4	4, 6, 8, 9, 12, 14, 15, 16, 18, 21, 22, 23, 25, 26, 27, 28, 30	2, 5, 17, 20, 24	3, 7, 10, 19, 29	1, 11	13
4-1	6, 9, 11, 16, 22, 26, 28	2, 4, 5, 8, 10, 12, 14, 15, 17, 18, 19, 20, 23, 24, 25, 27, 30	1, 3, 7, 13, 29		21
10-2	6, 11, 15, 16, 17, 21 26	4, 8, 10, 14, 18, 19, 20, 23, 27, 30	2, 3, 7, 9, 12, 13, 24, 25, 29	1	5, 22, 28

> ponents try to emphasize ways of understanding, expanding, and utilizing information and knowledge" (10-2, 14).

In some cases (see students 2 & 24), students moved from a Product to a Process orientation, moving through the blended category. This may be a result of overcompensation as a result of the class, or trying to provide the instructor with the perceived "correct" answer. While it is difficult to believe that students would completely abandon their view of science as a body of knowledge, the final journal entries may represent an extreme position that will be later modified to a more blended conception. While many students showed evidence of changing conceptions toward a more process-based orientation, other students remained in a consistent category throughout the class. Students 6, 16, and 26 remained in the "science as product" category, while others maintained views in the blended (students 19 & 20) or process category (students 3, 7, & 29).

Conclusions and Implications

The explicit teaching methods for introducing elementary preservice teachers to the NOS and SI within the context of a science methods course were successful in facilitating a shift from defining science in terms of a body of knowledge, or product, to a conception that accurately blends scientific products and processes. In some cases, students' conceptions shifted to a process only approach, potentially implying a wide pendulum swing of conceptions that may stabilize between incoming product and outgoing process orientations. In addition, student definitions of science became more sophisticated and elaborate as a result of the course, incorporating more of the terms championed by the science reforms. It should be noted, however, that these open-ended prompts did not specifically tap into student understandings of NOS and SI terms (i.e., tentative), leaving an incomplete picture of their understandings. Additional research using both open-ended and directed questions about NOS and SI may be more fruitful in completely understanding the learning that occurred.

Will teachers with a blended or process-based conception of science teach differently than those who persist in holding product-based views? The data from this investigation does not help answer this question since the students were not followed into their teaching placements. Anecdotal student information, however, suggests that the course increased their confidence and interest in science teaching and that a process-orientation to science provided a mechanism to integrate science with other subjects. Thus, it can be speculated that a blended or process-based conception of science may give elementary preservice teachers a context for learning and teaching science and may increase the likelihood that they will employ teaching methods that will assist in their students' understanding of NOS and SI.

References

American Association for the Advancement of Science (AAAS): 1989, *Science for All Americans: Project 2061*, Oxford University Press, New York.

AAAS: 1993, *Benchmarks for Science Literacy: Project 2061*, Oxford University Press, New York.

Bransford, J. D.: 1979, 'The Role of Prior Knowledge', *Human Cognition: Learning, Understanding and Remembering*, Wadsworth, Belmont, CA, pp. 129–165.

Gess-Newsome, J.: 1999, 'Teachers' Knowledge and Beliefs about Subject Matter and its Impact on Instruction', in J. Gess-Newsome & N. G. Lederman (eds.), *Examining Pedagogical Content Knowledge: The Construct and its Implications for Science Education*, Kluwer Publishing, Dordrecht, The Netherlands, pp. 51–94.

Gess-Newsome, J. & Lederman, N. G.: 1993, 'Preservice Biology Teachers' Knowledge Structures as a Function of Professional Teacher Education: A Year-Long Assessment', *Science Education* **77**(1), 25–45.

Gess-Newsome, J. & Southerland, S. A.: 2000, 'Addressing Issues of Inclusion in an Elementary Science Methods Course', in S. E. Wade (ed.), *Preparing Teachers for Inclusive Education: Case Pedagogies and Curricula for Teacher Educators*, Lawrence Erlbaum Associates, Mahwah, NJ, pp. 77–100.

Lawrence Hall of Science: 1981, *Swingers*, Berkeley, CA.

Lederman, N. G.: 1998, 'The State of Science Education: Subject Matter without Content', *Electronic Journal of Science Education* **3**(2), 1–12.

Lederman, N. G.: 1992, 'Students' and Teachers' Conceptions of the Nature of Science: A Review of the Research', *Journal of Research in Science Teaching* **29**(4), 331–359.

Lederman, N. G. & Abd-El-Khalick, F.: 1998, 'Avoiding De-Natured Science: Activities that Promote Understandings of the Nature of Science', in W. McComas (ed.), *The Nature of Science in Science Education: Rationales and Strategies*, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Lederman, N. G., Gess-Newsome, J., & Latz, M. S.: 1994, 'The Nature and Development of Preservice Teachers' Conceptions of Subject Matter and Pedagogy', *Journal of Research in Science Teaching* **31**(2), 129–146.

National Research Council: 1996, *National Science Education Standards*, National Academy Press, Washington, DC.

Rubba, P. & Andersen, H.: 1978, 'Development of an Instrument to Assess Secondary School Students' Understanding of the Nature of Scientific Knowledge', *Science Education* **62**(4), 449–458.

Sneider, C. I.: 1985, *Oobleck: What Do Scientists Do?: A Teachers Guide*, Lawrence Hall, Berkeley, CA.

Southerland, S. A. & Gess-Newsome, J.: 1999, 'Preservice Teachers' Views of Inclusive Science Teaching as Shaped by Images of Teaching, Learning, and Knowledge', *Science Education* **83**, 131–150.