

An Instrument To Assess Views Of Scientific Inquiry: The VOSI Questionnaire

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Abstract

Because teachers and students are to develop sound epistemological views of science (nature of science [NOS] and nature of scientific inquiry [NOSI]), assessments are needed to understand these views and how they develop. Much attention has focused on developing knowledge and pedagogical expertise in teaching NOS. The VNOS instrument has been paramount in advancing our understanding and needs of teachers and students. Currently, we lack similar understanding about views and needs regarding NOSI. If teachers are to teach *about* scientific inquiry, what is their knowledge base? What are students' views? How do we know if instruction is effective in advancing desired conceptions about what scientists do? In response to these questions, we have developed a valid, open-ended instrument that assesses views of scientific inquiry [VOSI]. The purpose of this paper is to describe the framework upon which the VOSI instrument is grounded, present a pool of items with rationale, describe administration and analysis procedures, and describe typical responses we have received that provide insights into views of NOSI.

Paper presented at the annual meeting of the National Association for Research in Science Teaching, March 30-April 2, 2008. Baltimore, MD.

Paper available at: <http://homepages.wmich.edu/~rschwart/>

Introduction

To be scientifically literate, individuals not only need conceptual knowledge of science subject matter, but also sound epistemological views about science that are consistent with current perspectives. Epistemological views of science involve one's view of scientific knowledge as a way of knowing and explaining the natural world (nature of science, NOS) and one's view of the nature and rationale of the processes through which that knowledge is constructed and justified (nature of scientific inquiry, NOSI). To be clear, the National Science Education Standards [NSES] (NRC, 1996, 2000) and Benchmarks for Science Literacy (AAAS, 1993) highlight scientific inquiry as integral to scientific literacy. Within the content standards for Science as Inquiry, students in grades K-12 should develop: (1) Abilities necessary to do inquiry, and (2) Understandings about scientific inquiry (NRC, 2000). The standards related to "Understanding about scientific inquiry" relate to aspects of what/why scientists work as they do and how knowledge is accepted within the scientific community. These aspects describe NOSI.

The Problem

Because teachers and students are to develop sound conceptions of NOS and NOSI, assessments are needed to understand their views. Much attention has focused on developing knowledge and pedagogical expertise in teaching NOS. The VNOS instrument (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) has been paramount in advancing our understanding and needs of teachers and students. Currently, we lack similar understanding about views and needs regarding NOSI. If teachers are to teach *about* SI, what is their knowledge base? What are students' views? How do we know if instruction is effective in advancing desired conceptions about what scientists do? In response to these questions, we have developed a valid, open-ended instrument that assesses views of scientific inquiry [VOSI]. The purpose of this paper is to

describe the framework upon which the VOSI instrument is grounded, present a pool of items with rationale, describe administration and analysis procedures, and describe typical responses we have received that provide insights into views of NOSI.

Why the distinction between NOS and NOSI?

The literature seems void of studies reporting on learners' understandings of NOSI *and* NOS. This is perhaps because NOS and NOSI or science processes are often conflated or combined under a more general "students' understandings of science." Notions about the methods of science, for example, are often placed under the umbrella of "NOS." For the purposes of clarity regarding the focus and utility of the VOSI instrument, we distinguish between NOS and NOSI, yet recognize this distinction as incomplete, with areas of overlap and connectivity. NOS aspects are those that pertain most to the *product* of inquiry, the scientific knowledge. NOSI aspects are those that pertain most to the *processes* of inquiry, the "how" the knowledge is generated and accepted. This distinction is further supported by the NSES (1996), "There are content standards for "Science as Inquiry" and separate content standards for "History and Nature of Science."

Theoretical Framework for The Nature of Scientific Inquiry

Like NOS, the meaning of "science as inquiry" has been debated for decades, and precise descriptions of what inquiry means for science education seem to vary as much as the methods of inquiry. Scientific inquiry refers to the characteristics of the processes through which scientific knowledge is developed, including the conventions of development, acceptance, and utility of scientific knowledge. The National Academy of Sciences (2002) has identified "guiding principles for scientific inquiry" that serve a common basis across disciplines of research including political science, geophysics, and education. These principles are similar to the items

described by the NSES as “skills of inquiry” (e.g. identify a question that can be answered through scientific investigations; design and conduct a scientific investigation; use appropriate tools and techniques to gather, analyze, and interpret data”(NRC, 2000, p. 19) and “fundamental understandings about scientific inquiry (e.g. “different kinds of questions suggest different kinds of scientific investigations; current scientific knowledge and understanding guide scientific investigations”(NRC, 2000, p. 20). To highlight the importance of understanding the nature of scientific inquiry, *The Benchmarks for Science Literacy* emphasizes what students should *know* in relation to inquiry, rather than skills of inquiry.

The NRC (2000), AAAS (1993), the NAS (2002), science educators (e.g. Chinn & Malhotra 2002; Flick & Lederman, 2004; Minstrell & van Zee, 2000; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Windschitl, 2004), and researchers who have explored scientists in practice (e.g. Dunbar, 2001; Knorr-Cetina, 1999) offer descriptions about scientific inquiry that provide the framework for our description of NOSI. The commonalities we identify in this collection of work are agreed upon aspects of NOSI that are also relevant and important for science education. These aspects are not newly identified, as they are consistent with those set forth in general terms by Joseph Schwab 45 years ago (Schwab, 1962). The general aspects of NOSI include: a) Questions guide investigations, b) multiple methods of scientific investigations, c) multiple purposes of scientific investigations, d) justification of scientific knowledge, e) recognition and handling of anomalous data, f) sources, roles of, and distinctions between data and evidence, and g) community of practice.

- a) Scientific questions guide investigations. “Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world” (NRC, 2000, pg. 20). Contrary to the common “step one” of the scientific method, all investigations do not begin with the statement of a hypothesis. Before hypothesizing or considering what information may be helpful to gain understanding, scientists must ask questions.

- b) Multiple methods of scientific investigations. “Scientists use different kinds of investigations depending on the questions they are trying to answer” (NRC, 2000, pg. 20). There is no single “scientific method” that all scientists follow to produce valid knowledge. Studies of scientists in practice demonstrate that investigative approaches vary in form (e.g. Knorr-Cetina, 1999). An experimental approach involves hypothesis testing through identifying and controlling variables of importance to the question, and manipulating one variable at a time to determine resultant effects. Experimental investigations are most similar to “the scientific method” that persists in textbooks and on classroom posters. Another type of approach does not involve manipulation of variables, either because manipulation is not possible or is not desirable to answer the question of interest. This approach involves observations of natural phenomena, void of direct disturbance by the observer, can result in valid scientific understanding of the phenomena. Questions guide all these approaches. However, scientists may follow different procedures to address the same question.
- c) Multiple purposes of scientific investigations. In general, “scientists aim to build and revise theoretical models with unobservable mechanisms” (Chinn & Malhotra, 2002, p. 188). The questions scientists choose to pursue stem from many sources and can serve many purposes. Why scientists choose to investigate certain questions may relate to curiosity, social impact, economy, practicality, or any variety of other reasons. “Current scientific knowledge and understanding guide scientific investigations.” (NRC, 2000, pg. 20). The work of scientists may help solve a socially-based situation (such as disease), may be necessary to develop desired technology, may improve human condition, or may advance basic understanding of our world.
- d) Justification of scientific knowledge. “Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories” (NRC, 2000, pg. 20). The processes of negotiating meaning and gaining consensus involve building justification for claims. Evidence, consistency, and recognition of alternatives are associated elements. Nonetheless, scientists who ask similar questions and follow similar procedures may validly make different conclusions. Further, scientists who examine the same data may justifiably come to different conclusions. As stated by a scientist in a study by Osborne et al. (2003) “‘it is crucial to know that scientific data does not stand by itself, but can be variously interpreted’ (PS1)” (p. 708).
- e) Recognition and handling of anomalous data. Investigations are guided by current knowledge and theory, thus scientists have expectations. Recognizing when observations do not fit expectations is a critical part of progress in science. Anomalies spark more questions and drive further investigations. Authentic science involves a variety of approaches to handling anomalous information (Chinn & Brewer, 1993, 1998). These include rejection (error negates anomaly), ignoring the anomaly, inclusion without explanation, abeyance (set aside), acceptance with theory change, reinterpretation of data, peripheral theory change.
- f) Distinctions between data and evidence. Data and evidence serve different purposes and come from different sources. Data are observations scientists gather during the course of an investigation. They can take a variety of forms (e.g. numbers, descriptions, photographs, audio, physical samples, etc). Evidence is a product of data analysis and interpretation. Evidence is

directly connected to a question and claim. How data are analyzed and interpreted depends on the questions being addressed and currently accepted practices.

- g) Community of practice. “Scientists review and ask questions about the results of others’ work....Science advances through logical skepticism” (NRC, 2000, pg. 20). Scientific inquiry is embedded within a community. There are multiple communities within the broader community of science (Knorr-Cetina, 1999). Practices and standards for developing and accepting scientific knowledge are established within these communities. Communication and peer review impact what and how science progresses.

Development of the VOSI instrument

The need for an open-ended instrument to examine learners’ conceptions about scientific inquiry is parallel to prior needs related to NOS. We have developed the VOSI through a process and form similar to the VNOS. Items were developed based on the aforementioned aspects, reviewed by a panel of science educators and scientists, and pilot tested. Since 1999, VOSI items have been used in a variety of research studies and evaluation projects. We now have VOSI forms appropriate for elementary and middle school children, secondary students, college students, preservice and inservice teachers, and scientists.

The original VOSI questionnaire was a 9-item survey, developed for use in a study of grade nine students’ views of NOS and NOSI (Schwartz, Lederman, & Thompson, 2001). This study served as a pilot of the first VOSI form [VOSI-1]. The items were examined and validated by a panel of science educators. The items were then administered to a group of 10 grade nine students, who were also interviewed. Only minor revisions were necessary, based on student comments, before administering the VOSI-1 questionnaire to the full sample of 115 ninth graders. The students took approximately 30 minutes to respond to the nine items. Twenty students were randomly chosen for follow up interviews. The interviews serve to ensure valid interpretation of the respondent’s written statements. Analysis proceeds in a similar fashion as

the VNOS, with the targeted aspects guiding initial review, but seeking descriptors and emergent themes.

Additional VOSI items have been developed and used to explore NOSI views of preservice teachers, inservice teachers, elementary and middle school students, college students, and scientists (Table 1). To date, hundreds of teachers and thousands of students have responded to the VOSI. The VOSI forms we have used in research and evaluation contain five to nine items each, targeting a variety of the NOSI aspects that guided their development. VOSI items have been reviewed by science educators, scientists, and science teachers; and have demonstrated utility in eliciting descriptions and examples of how respondent's understand targeted aspects about inquiry. We provide a pool of items in this paper, their purpose, and typical responses representing a range of conceptions (Table 2). Specific VOSI forms for use in research, evaluation, or instruction can be obtained by contacting the authors.

Administration and Interviews

Administration, interviews, and analysis are similar to the guidelines of Lederman et al. (2002) for the VNOS instrument. The most desirable manner to administer the survey is in a controlled setting, where respondents provide their statements without communication with others. Approximately 20-60 minutes are needed, depending on the sample and VOSI form. Ideally, all respondents are interviewed, using the written responses as a guide. For large groups, a random selection of about 20% is usually sufficient to establish confidence in reliability of data interpretation. Interviews typically range from 15-45 minutes.

Analysis

There is not a one-to-one correspondence of item to aspect, and, as such, the VOSI responses for each individual should be considered holistically in the development of a profile.

Targeted NOSI aspects serve to guide initial coding (Miles & Huberman, 1994). Responses are reviewed and coded with descriptors related to each targeted NOSI aspects. For example, regarding the aspect of “justification of scientific knowledge,” typical descriptors include “requires repetition,” “must explain all data,” and “requires proof the answer is true.” Emergent codes are also sought, according to the methods of Bogdin and Biklen (1992). After initial analysis, the responses are reviewed several more times for further reduction, clarification and consistency. Interview transcripts are analyzed in the same manner, and then compared to the analysis of written responses. A final profile is developed for each individual. Rounds of analysis continue through constant comparison until data are sufficiently reduced and described. For Individual profiles can be pooled to generate a composite profile for larger samples, represented through percentages or frequencies. Profiles may be compared to desired descriptions of aspects to determine relative alignment of conceptions toward goals. If the VOSI is used to study the effects of an intervention, conceptual gains or change can be described through comparison of pre and post test profiles.

Sample VOSI Items

Table 2 contains sample VOSI items that target the specific aforementioned NOSI aspects or elicit ideas of other aspects. Secondary aspects, indicated in parentheses, are not specifically targeted through the item, but often emerge in the response. We describe the rationale for the item and typical responses. This item pool is not all inclusive and is not intended to be used as a VOSI version alone. The items represented here are selected from various forms. Alternative versions of the items and additional items are specifically selected for certain VOSI forms appropriate for specific audiences and purposes. Researchers who are interested in using the VOSI or CVS (below) should contact the authors for further information and forms.

Significance of assessing Views of Scientific Inquiry

The VOSI questionnaire elicits details of learners' ideas of what scientists do in the production of valid scientific knowledge. Understanding *about* scientific inquiry is an integral component of scientific literacy, along with NOS. The VOSI is useful alone, or in combination with the VNOS to gain in-depth insights into respondent's epistemological views of science. The VOSI targets aspects unique from, but complementary to, the VNOS instrument. Responses on the VOSI provide descriptors and examples, as opposed to scores (numbers) or dichotomous categories (naïve/informed). In addition to being useful for research and evaluation purposes, VOSI items and responses are useful for generating discussion in science classes, professional development, and science education programs. Given the great emphasis on developing skills and understanding of inquiry, the VOSI questionnaire can advance our understanding of learners' conceptions and how they develop.

Assessing Young Children's Views of Science

The items presented in Table 2 are administered through a written format with follow up interviews. However, there are obstacles specific to Pre-K and early elementary children that make a written assessment impractical. These obstacles include: limited reading abilities, limited abilities to express thoughts through writing, developmental level of the vocabulary, and delayed processing. These young children or children who are non-readers have ideas about science that can be explored through a more conversational approach (Lederman & Lederman, 2005). The Young Children's' Views of Science [CVS] is an oral assessment of views of nature of science and nature of scientific inquiry (Lederman, 2008). For practical reasons, this single oral assessment elicits ideas of both NOS and NOSI. The CVS consists of two parts (Table 3). Children are gathered into small groups (around 4 children per group)

and asked to talk about what they think science is and what scientists do. In Part 1, the interviewer asks the children a set of questions to establish that the child has some knowledge of what Science is as opposed to other disciplines. Establishing that the student has some understanding (in whatever capacity) of the domain of science is necessary so that when the child's opinions are asked during the rest of the interview, the interviewer has faith that the child is referring to science. Part I questions also serve to establish a conversational rapport with the students. We suggest disregarding the rest of a child's responses if it becomes clear that the child's opinions are about something they clearly have no knowledge about. If the interviews are conducted over a two-day period then it may be possible to not involve these students in the second part. Part 2 consists of five main questions and an alternative (Table 3). It is important to keep in mind that this set of questions probes children's ideas about both NOS and NOSI. Analysis is guided by targeted aspects of both. The third author of this paper should be contacted for further information on administration and analysis.

Table 1. VOSI forms and select references for different audiences

Target audience	VOSI forms	Select References
Preservice teachers	VOSI-270, E	Schwartz, R. S. (2007). <i>Beyond Evolution: A thematic approach to teaching NOS in an undergraduate biology course</i> . Paper presented at the Annual meeting of the National Association for Research in Science Teaching, New Orleans, LA. [manuscript in review]
Inservice teachers (K-12)	VOSI-2, 3, 4, 270, E	<p>Lederman, N.G., Lederman, J.S., Kim, B.S., & Ko, E.K. (2006). <i>Project ICAN: A program to enhance teachers' and students' understandings of nature of science and scientific inquiry</i>. A paper presented at the Annual Meeting of the National Association for Research in Science Teaching, San Francisco, CA. [http://www.projectican.com/]</p> <p>Akerson, V., Hanson, D., & Cullen, T. (2007). The influence of guided inquiry and explicit instruction on K-6 teachers' views of nature of science. <i>Journal of Science Teacher Education</i>, 18, 751-772.</p> <p>Grant Evaluation: <i>Project ICAN: Inquiry, Context, and Nature of Science</i> [NSF] PI: Norm Lederman, Illinois Institute of Technology, 2001-2007.</p> <p><i>Warren Township Math-Science Partnership</i>. [United States Department of Education]. PIs: David Abler, Illinois Mathematics and Science Academy; Norm Lederman, Illinois Institute of Technology. 2004-2006.</p>
Early Elementary students (preK-2)	Young Children's Views of Science [CVS]	<p>Lederman, J. S. (2008) An oral assessment of young children's views of science [CVS]. Unpublished document. Illinois Institute of Technology.</p> <p>Lederman, J.S., & Lederman, N.G. (2005). <i>Teaching and assessing nature of science and scientific inquiry with young children</i>. A workshop presented at the Annual Meeting of the National Science Teachers Association, Dallas, TX</p>
Elementary students	VOSI-E	<p>Ko, E.K., & Lederman, N.G. (2005). <i>How is students' understanding about inquiry related to their performance through inquiry-based science lessons?</i> A paper presented at the Annual Meeting of the Association for the Education of Teachers in Science, Colorado Springs, CO.</p> <p>Grant Evaluation: <i>Project ICAN: Inquiry, Context, and Nature of Science</i> [NSF] PI: Norm Lederman, Illinois Institute of Technology, 2001-2007.</p>

Middle school students	VOSI-M, E, 2, 3	<p>Lederman, N.G., Lederman, J.S., Kim, B.S., & Ko. E. (2007). <i>Project ICAN: Linking teachers' knowledge and practice related to nature of science and scientific inquiry</i>. A paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL</p> <p>Lederman, N. G., Schwartz, R. S., Lederman, J., Matthews, L., & Khishfe, R. (2002). <i>Project ICAN: A teacher enhancement project to promote teachers' and students' knowledge of scientific inquiry and nature of science</i>. Symposium presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA</p> <p>Grant Evaluation: <i>Project ICAN: Inquiry, Context, and Nature of Science</i> [NSF] PI: Norm Lederman, Illinois Institute of Technology, 2001-2007.</p>
High school students	VOSI-1, 4, Sec.	<p>Schwartz, R. S., Lederman, N. G., & Thompson, R. (2001). <i>Grade nine students' views of nature of science and scientific inquiry: The effects of an inquiry-enthusiast's approach to teaching science as inquiry</i>. Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.</p> <p>Lederman, N.G., Lederman, J.S., Kim, B.S., & Ko. E. (2007). <i>Project ICAN: Linking teachers' knowledge and practice related to nature of science and scientific inquiry</i>. A paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL</p> <p>Grant Evaluation: <i>Project ICAN: Inquiry, Context, and Nature of Science</i> [NSF] PI: Norm Lederman, Illinois Institute of Technology, 2001-2007.</p> <p><i>Warren Township Math-Science Partnership</i>. [United States Department of Education]. PIs: David Abler, Illinois Mathematics and Science Academy; Norm Lederman, Illinois Institute of Technology. 2004-2006.</p>
Scientists	VOSI-Sci	<p>Schwartz, R. S. (2004). <i>Epistemological views in authentic science practice: A cross-discipline study of scientists' views of nature of science and scientific inquiry</i>. Doctoral dissertation. Oregon State University, Corvallis, OR.</p>

Table 2. Sample VOSI Items

VOSI Items	Targeted aspect
[These items represent the pool of VOSI items. Many of these items have different variations, depending on the target audience. Each VOSI form contains a combination of specifically selected items.]	(secondary aspect)
<p>What types of activities do scientists (e.g., biologists, chemists, physicists, earth scientists) do to learn about the natural world? Discuss how scientists (biologists, chemists, earth scientists) do their work.</p> <ul style="list-style-type: none"> This question targets views of what scientists do when they “do science.” Typical responses describe activities such as “experiment, ask questions, make hypotheses, collect and analyze data, make observations, etc.” Responses that are too general include “do research; find answers to their questions” Interview follow up should probe for more specific examples of what research is and how scientists go about finding answers. What is required for a good answer? Response indicative of more naïve or narrow views of scientific activity include: <ul style="list-style-type: none"> <i>“Do experiments to prove their ideas/hypotheses are right.” [preservice]</i> <i>“Scientists follow the scientific method.” [middle school student]</i> <i>“Scientists work in a laboratory.” [middle school student]</i> 	a, b, c
<p>How do scientists decide what and how to do their investigations? Describe all the factors that you think influence the work of scientists.</p> <ul style="list-style-type: none"> This question targets ideas about choices scientists make in topics and procedures. Where do their questions come from? How do they decide on procedures? Responses vary, from indicating scientists ask questions for no particular reason; or scientists ask questions about things that are curious; they ask questions in order to help the world; they focus on questions relevant to society and economic import: <ul style="list-style-type: none"> <i>“They make a question and get information about it. They have to test the question.” [8th grader]</i> <i>“Scientists decide to investigate things they are wondering about. They might investigate things to make things better.” [8th grader]</i> <i>“Three factors influence the work of scientists. Curiosity, the politics of society or culture, and economic forces in society...Most of us are driven, at least early on, by curiosity...It is also an idealistic and naïve approach to science. The fact of the matter is that nearly all, if not all, of science is paid for on the basis of politics or economic forces... [scientist]</i> 	a, b, c (e, g)
<p>What do you think a <u>scientific experiment</u> is? Give an example to support your answer.</p> <ul style="list-style-type: none"> This question is adapted from the VNOS-C questionnaire (Lederman et al., 2002). The main intent on the VOSI is for respondents to explicate their ideas of scientific experiment such that the use of the term in other responses is understood. Responses often include reference to purpose of science and may also suggest ideas of single or multiple methods. Responses to the scientific method item (#5 listed here) are informative as well. In the classic sense, “Experiment” is described as a specific step-wise procedure (the scientific method) that has controls, variables, and seeks cause/effect claims. <ul style="list-style-type: none"> <i>“Scientific experiment is a set of steps or processes used to reach a conclusion. It involves a hypothesis, controls, and a test.” [preservice elem/mid]</i> <i>“Manipulation of a variable in a defined setting in relation to an unmanipulated control or reference.” [scientist]</i> 	(b, c)

- In more general terms, “experiment” means anything that scientists do as they investigate. Respondents with a more general view tend to describe activities such as making observations, describing an object, taking measurements, and manipulating variables are included under the umbrella of “experiment”.
“...using different materials and resources to help us understand how something works. Ex: how to show how convection works, using a hot plate, water, and noodles, etc.” [preservice elem/mid]
“A scientific experiment is a broad term. It could be an investigation to gain new understandings or information. Or, it could also be an experiment done to verify that current understanding is correct.” [7th grade teacher]
- Other typical responses describe “experiment” as testing of a hypothesis or idea, something you conduct to explore a science topic, answers a question, requires replication, depend on context.
“...an act to prove a point. Ex: in biology we grew plant with and without fertilizer to see which grew stronger” [preservice elem/mid]
“Experiments in physics are different from experiments in astronomy because we can’t go and scoop up the stars and make changes. We can’t investigate particular variables in isolation.” [scientist]

(a) What does the word “data” mean in science?

f (d)

Data are observations. These observations could be qualitative or quantitative.

- A more acceptable response describes data as information gathered in the course of investigation:
“Data is information gathered through experimentation, whether it be calculations or some form of quantitative information, or qualitative such as the color change in a chemical reaction.” [middle school teacher]
- Typical narrow responses describe data as some form of quantification:
“Data are numbers only.” [preservice elem/mid]

(b) Is “data” the same or different from “evidence” ? Explain.

- This question asks for clarification of terms. Data and evidence are functionally different. Evidence is data that has been interpreted in light of a question. Not all data are evidence.
“Evidence comes from the data through analysis and supports a conclusion.” [secondary teacher]
“Data is information until it is interpreted, then it becomes evidence.” [middle school teacher]
- Typical narrow responses suggest that evidence is something nonnumerical or something that is only presented in a court of law.
“Evidence is the physical stuff, not numbers.” [preservice elem/mid]
“Evidence is only found in court.” [grade 9 student]

A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.

b (d)

(a) Do you consider this person’s investigation to be an experiment? Please explain why or why not.

- This question examines views of “experiment” as being a general scientific activity or a specific scientific procedure. This investigation is not an experiment. There is no manipulation of the teeth or food source. It is an observation of a natural state. The correlation between the teeth structure and food source is found through repeated observation, not experimentation.
- Respondents with a more general view of “experiment” will describe this activity as experimental because observations and conclusions were made.
“Yes [experiment] because she needed research, a question, and a conclusion.” [8th grader]

(b) Do you consider this person’s investigation to be scientific? Please explain why or why not by describing what it means to do something “scientifically.”

This investigation is / is not (circle one) scientific because....

- This question probes respondents’ views of what constitutes “scientific” activity. If they think all science must be conducted through experiments, and their view of experiment is that which involves manipulation of variables and use of controls, then they will not see this example as scientific (or experimental). Such a response is indicative of a narrow view of scientific inquiry. This response suggests a view that “the scientific method” is the only way to do science. Typical response indicating a narrow view of scientific inquiry:
*“Not scientific because...
... there was not a hypothesis.” [preservice]
...they did not change anything. They need to change the food source and see if the beak changes.” [9th grader]
...it was just an observation, not a test.” [8th grader]*
- A response that says this example is scientific, but not experimental is the desired response, provided their view of experiment is that involving variables and use of controls. This example is not an experiment (as described above) but it can be considered scientific because of the use of repeated observations, identification of a pattern, and inferred correlation based on the observations. Thus, the conclusions are based on observations of the natural world. Such a response is consistent with a broader and more acceptable view of scientific inquiry as consisting of many methods of science.

The “scientific method” is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results. Do you agree that to do good science, scientists must follow the scientific method?

b (c)

_____ **YES, scientists must follow the scientific method**

_____ **NO, there are many scientific methods**

- If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.
 - If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.
- This is a direct question about views of “scientific method.” Look for consistency between this response and the response in #3 above. The desired response is NO, with the explanation that investigations can take many forms depending on the question asked. Experiments involving manipulation of variables is one approach. Correlational and
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descriptive investigations that do not involve direct manipulation are also valid approaches.

“Scientists can follow different methods depending on what they want to answer.

Sometimes they do experiments and sometimes they can only make observations. Both are science because they both are from the real world.” [secondary teacher]

- If the respondent thinks there is only one scientific method, then they usually say that the experimental approach with hypotheses, variables, and controls is necessary for good science or to “prove their answer” or be “certain they are right.” Most often, answers allude to needs to establish cause/effect relationships.....otherwise, “It is just opinion.”
- Responses representing more narrow/naïve views]:
 - “I think this should be done because it gives good data and good results. It is a good method to make sure that science is being done great.” [preservice elementary]*
 - “So their experiment can be proven again or repeated.” [9th grader]*
- Responses may also suggest a single scientific method, but the description of that method may be broad such as: asking questions, making a procedure, collecting data, analyzing data, and making conclusions. Their explanation of why this method is the only method is very important for understanding their position on “scientific method.” Inclusion of the description in the question helps to avoid confusion, but responses are not always consistent. Analysis must consider respondents’ explanation. Consideration of description of “experiment” is also important.
- Interview follow up should ask for clarification through examples.

(a) When scientists are ready to report their results to other scientists, what kind of information do you think they need to include in their report in order to convince others that they have a good conclusion? Be as specific as possible. Try to give an example

d (c, f, g)

- This question targets views of justification. Responses often make reference to purpose of science, evidence, and the role of scientific community. Interview follow up should ask for clarification of criteria, especially terms such as “proof,” “experiment”, “evidence” and “test.”
- Typical responses indicating more naïve views suggest that with sufficient data, scientists show they have the right answer. They also suggest that the scientific method is necessary:
 - “Scientists have to have evidence to prove it works.” [8th grader]*
 - “Information they need to convince others that they are right is evidence and correct data from the scientific method.” [preservice elementary]*
- Responses often focus on justification criteria such as results being repeatable, presenting statistical support, results are consistent, predictable, clear evidence to support, alternatives are addressed
 - “Scientists have covered all the angles and gotten consistent results.” [preservice elementary]*
 - “A new scientific claim in astronomy is the existence of a new form of energy called ‘dark energy’ which in fact comprises most of the total mass-energy of the universe. The acceptance of this claim has required investigation by several different teams of astronomers using different techniques. The claim must also be consistent with all existing data.” [scientist]*
 - “What makes it valid is enough of your peers saying it is valid. They are basing their opinion on their experiences of what is good and what is not.” [scientist]*

(b) Do you think all types of scientists have the same requirements as you stated in (a) for justifying and accepting scientific claims? Give examples.

- This item asks respondents to consider different types of science and scientists. Their
-

response to part (a) may be contextualized within a particular domain or content area that does not represent all of science. For example, a response to part (a) may indicate the requirement of statistical measures, but in part (b) the respondent may acknowledge that statistics may not be appropriate for some types of science. In those cases, evidence may take a different form. This type of response indicates a more sophisticated understanding of science and justification. A more narrow view would be indicated by stating all claims must be justified with statistical measures to be acceptable.

(a) If several scientists, working independently, ask the *same question* and follow the *same procedures* to collect data, will they necessarily come to the *same conclusions*? Explain why or why not. a, d, g

- This question targets views about interpretation and acceptance of data. The idea here is that data interpretation is informed by the questions AND the investigator. If working independently, different conclusions may be drawn from the same set of data because scientists may view the data differently, weighing more heavily one type of information over another, or putting the pieces together in a different (yet still valid) way. Responses indicate views about influences on scientific investigations, justification, and science as a community.
- This question also probes respondents' views of subjectivity in science (a NOS aspect). A naïve response would suggest that if the same procedures are followed then they would get the same result unless someone did something wrong in the procedure. Such a view suggests the data are collected and interpreted without creative or subjective influence of the scientist.
- The following response suggests that the procedure determines the outcome, neglecting the role of inference and justification.
"They should. It's the same procedure." [grade 12, Christi]
- In contrast, the following response leaves room for data interpretation and the role of subjectivity in justifying conclusions.
"No, they may have a different view on what happened and why." [grade 12, Ashley]

(b) If several scientists, working independently, ask the *same question* and follow *different procedures* to collect data, will they necessarily come to the *same conclusions*? Explain why or why not.

- Similar to (a) but often respondents say that because different procedures are followed that the data may be different, and therefore, conclusions could be different. The point is to probe their views of how questions and procedures influence findings. That the data are collected and interpreted in light of a question, but through the lens of the researcher.
"They will be different. They have different procedures." [grade 12, Christi]
"No, they can interpret things very differently." [grade 12, Ashley]

These responses suggest slightly different views. Responses to the other parts of this question usually help with categorizing these statements. The first one, written by the same individual as part (a), suggests that procedures are the key to the outcome. The second response suggests that data interpretation can vary depending on the scientist.

(c) Does your response to (a) change if the scientists are *working together*? Explain.

- This question follows up typical responses to (a) and (b) that state there are differences because the scientists don't work together. Here, if they are working together, is there the possibility of still getting different conclusions. Yes, but consensus may be reached through discussion. It won't necessarily be reached, but is more likely because the research group or community should have a common goal.
-

“If they work together, they will do the same thing and get the same answer.” [grade 12, Christi]

“I think they might get the same answer because they are working together. But they might still get different results.” [grade 12, Ashley]

(d) Does your response to (b) change if the scientists are *working together*?

Explain.

- Same as (c) in that they will more likely have a common goal or shared perspective.

However, they still may view the data in different ways.

“Yes, they would get the same answer because they follow the same procedure and have the same information.” [grade 12, Christi]

“Not necessarily. They could still interpret the data differently. There is a better chance they would agree because they could talk about their ideas together.” [grade 12, Ashley]

Scientists sometimes encounter inconsistent findings (anomalous information).

e (d, g)

(a) How are anomalies identified in science? (i.e. What is considered “inconsistent” in scientific research?) Provide an example, if possible.

(b) What do you think scientists do when they find an anomaly?

(c) Do you think all scientists identify and handle anomalous information this same way? Why or why not?

(d) How do *students* typically identify and handle anomalies (inconsistent data) in a science classroom?

(e) Do you think students and scientists handle anomalies in the same way? Explain.

- This form of the item is most useful for preservice teachers, inservice teachers, and scientists. An alternate version is available for K-12 students and non-teachers.
- This question probes views of anomalies in science and how they are identified and dealt with. A response suggesting that anomalies are necessary for scientific progress is a more “informed” view than one that suggests anomalies are “mistakes” from procedural errors. The notion that anomalies are important for scientific progress is often overlooked in science classrooms. The requirement for describing “experimental error” to explain away outliers may be problematic to acknowledging anomalies as interesting, exciting, and fundamental features of scientific inquiry. Responses are coded based on emergent themes.
- Typical themes related to recognition and handling of anomalies in authentic science include: repeat the test (true anomaly or error?); progress; excitement; assimilate into existing theory or model; modify existing theory or model; reject existing theory; develop new theory; ignore; delete; include data without explanation; recognize and explain as error.
- Sample responses:

Repeat test: *“You look to verify if the equipment is running properly or if you made a blunder in preparing the sample....You look for obvious mistakes...If you can’t seem to account for this anomaly on that basis, then you have to begin to question the premise or hypothesis that is the premise behind the experiment...that nature is not behaving in accordance with whatever your expectations were...” [scientist]*

Progress: *“That is when you come up with the new stuff, is when you absolutely can’t rule out the possibility that there is something new...some bit of biology there. That is the fun stuff.” [scientist]*

Reject theory: *“You can only disprove. With one exception, if it is repeatable, the theory is gone.” [scientist]*

“[scientists] will go back and re-do their work to find any errors they may have made or start over with a new idea.” [preservice elementary]

Ignore or delete: *“More tests are conducted to see why this happened. Some scientists may not include the anomaly because it doesn’t go along with their results.” [preservice elementary]*

- Typical themes related to anomalies in school science include: repeat the test (find error source); ignore; delete; change to fit expectations; recognize and explain as error; recognize without explanation; give up.

“[students] usually assume they must be wrong and take the previous finding’s word. They don’t have confidence to accept their own findings.” [preservice elementary]

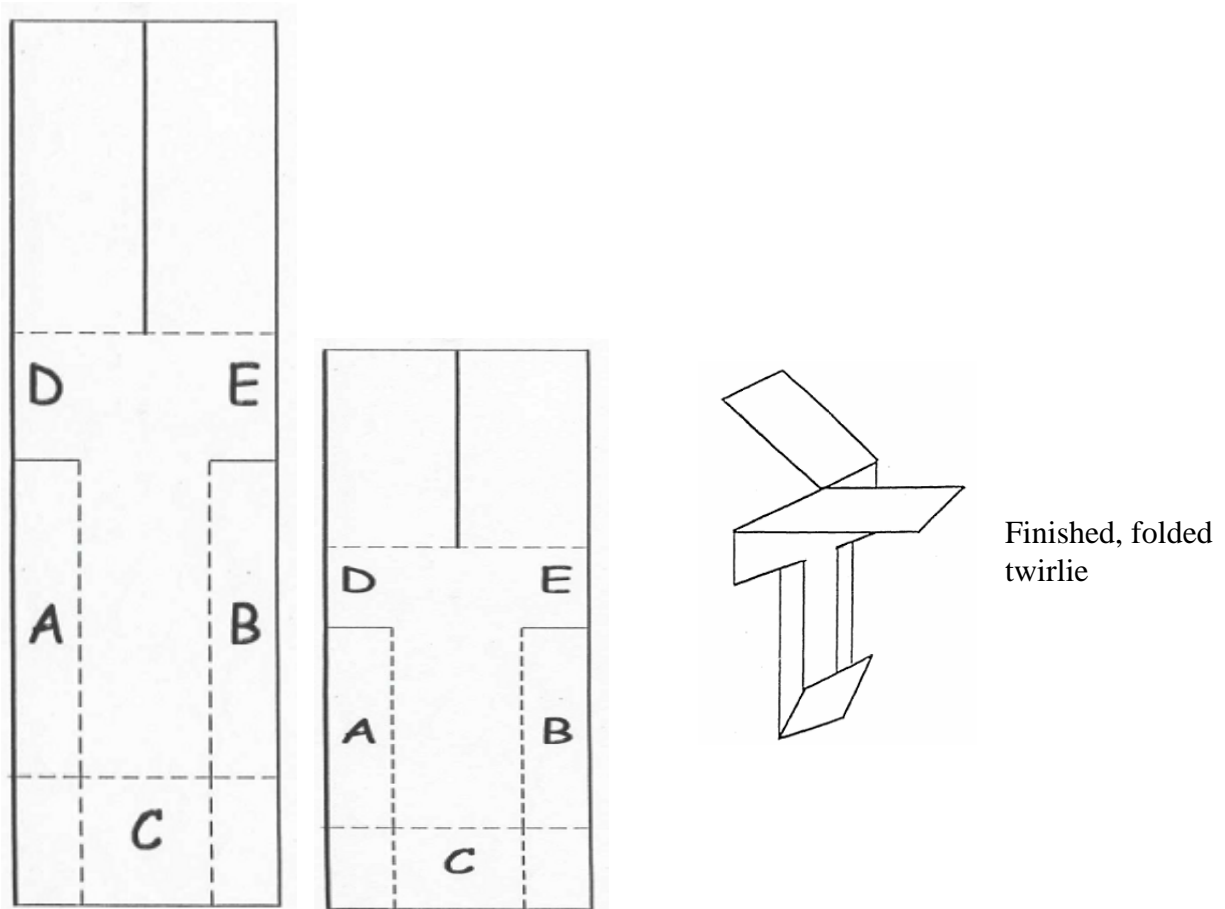
“[students] may not realize that anomalies happen and they may not have the time or tools to do further research...” [preservice elementary]

“Students often look at anomalies as design flaws or measurement errors...” [middle school teacher]

Table 3. An oral assessment of young Children's Views of Science [CVS] (Lederman, 2008)

Part 1	Can you tell me something you know about science? Do you ever learn about science in school? Can you tell me what you learned? Have you ever learned about science somewhere else other than school? Where? What did you do? How is science different from other things you learn about? You have been telling me many things about science. So, What is science? What is a Scientist? What do they Do ? How do they do their work? Have you ever seen a scientist? Do you know one? What do they do?
Part 2	1. Tell the students that you are going to show them something and that you want them to watch very carefully. Drop the two different size paper helicopters (figure 1) one at a time. Ask each child to make one observation and then one inference about what they just saw. Then ask: Was what you just watched a scientific investigation? Why? Why not? If they say it wasn't, ask them what they would need to do to make it into an investigation.
	2. There was a woman who loved birds. She traveled around the world to study them. As she traveled she noticed that birds had many differently shaped beaks. For example, some were long and thin, some were big and sharp, and some were tiny and short. She also observed that birds ate different types of food. She asked the question, "Is there a connection between birds' beak shapes and the types of food they ate?" (a) Do you think she was working like a scientist? Why or why not? (b) Do you think her work was an experiment? Why or why not? (c) What should she do next to answer her question?
	3. How many of you know something about Dinosaurs? (Students will immediately start telling you everything they know about Dinosaurs...you can get some control of the discussion by saying: Each of you tell me one thing you know about dinosaurs...then go on to ask the following questions) (a) How do scientists know that dinosaurs really lived since there are no dinosaurs around anymore and no one has ever seen them? (b) What do scientists think dinosaurs looked like? Why do scientists think they look this way? (c) Scientists don't always agree on the reasons about what happened to make the dinosaurs all die away. Why do you think they don't agree? (d) If your friend said that he knew the reason for what happened to the dinosaurs, what would he have to do to make scientists believe him? Why?
	[Alternative Question: If the students are too distracted by the dinosaur question then you might choose to use this one instead:] How do the people who predict the weather on TV use science? How do they decide what the weather will be today? Weather reporters don't always agree with each about the weather? Why do you think they disagree?
	4. You have all told me know about a lot of different facts and ideas about science. (a) Do you think scientists will change their minds about these same science facts years from now? Why? (b) Can you give me an example of some science idea that might change in the future?
	5. Do you think that scientists are creative when they do their work? Can you give me an example? When do you think they are creative when they are doing an investigation?

Figure 1. Paper helicopter templates (a.k.a. Twirlies)



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