SMS 491/EDW 472

Teaching Science by Ocean Inquiry

Spring 2008

PEDAGOGY PACKET

A BRIEF INTRODUCTION TO TEACHING AND TO INQUIRY
TEACHING: A BRIEF SUMMARY

Who is involved?
Teaching is an ongoing, organized, reflexive process that directly involves the instructor and students, as well as the social environment and material environment (e.g., textbook, www, and material resources) in which the instructor and students interact. Indirectly, the school organization, community, and other practitioners (e.g., via textbooks they have written) are also involved in the teaching process.

Knowledge creation
In the teaching process the instructor and students jointly create knowledge.

Knowledge distribution
Knowledge is viewed as being distributed over the minds, bodies, activities and culturally organized settings (i.e., resource area, classroom, community) of instructor and students.

Instructor’s role
The instructor’s role as participant in the joint construction of knowledge includes monitoring the conceptual changes of the students, in order to determine how and when to influence the various streams of activity that flow together in the classroom. These streams may include such activities as: exploration of question-evoking environments (in the laboratory or on a field trips); consultation of textbook knowledge, ”teacher’s knowledge”, and experts’ knowledge (on field trips or with guest speakers); students’ written creation of answers to their own questions and the teacher’s questions; contribution to small or large-group classroom discussions; and students’ journal keeping.
**THE KEY TO GOOD SCIENCE TEACHING**

**Meaningful transactions**

Good teaching is a complex process. If there is one key, it is the fact that a good teacher creates the greatest possible number of opportunities for each student to have varied and “meaningful transactions” that contribute to his or her learning. A transaction is an interaction between two entities in which both entities are changed. For this transaction to be meaningful for the student, it must enable the student to be affected in such a way that s/he constructs some additional personal knowledge, connecting it mentally to his/her prior set of personal knowledge.

**Transactions with what?**

A good science teacher arranges opportunities for each student to interact in and out of the classroom in focused, interesting, meaningful ways with many other entities (many of which are not mutually exclusive):

- Objects (natural and human-made)
- Actual phenomena (scientific and social)
- Films, videotapes, computer simulations of phenomena
- Knowledge of science disciplines that has been constructed by scientists
- Science data
- Other students
- Teachers
- Parents
- Other community members
- Scientific experts
- Tools (apparatus, computers, WWW, textbooks, scientists reference books, camcorders, etc.)

**Examples**

*Student-data interaction.* When the student interacts meaningfully with scientific data, the student changes the data (rounds it off, substitutes it in formulas, tabulates it, graphs it) so that patterns may stand out in it. The student does not merely follow a cookbook-style set of instructions. She or he thinks about why she or he is carrying out these operations on the data. The student tries to interpret the data – use it to draw conclusions about the scientific phenomenon it describes. The student does not remain unchanged by this interaction. She or he becomes more familiar with the data and the phenomenon it describes (and possibly with data processing techniques, also).

*Student-student interaction.* When a student interacts meaningfully with one or more other students in a laboratory team in a discussion group, she or he discusses with them questions, strategies for pursuing answers to questions, observations, interpretations, and conclusions. The student learns new things and changes his or her ideas as a result. The other students are changed in similar ways.

*Teacher-student interactions.* When a teacher and student interact meaningfully (perhaps while the student asks the teacher questions about a scientific phenomenon), the student changes his or her ideas, learning from the teacher. The teacher is not unchanged by this interaction. She or he may learn more about the student’s personal knowledge framework, more about teaching, and more about the scientific phenomenon.
INQUIRY AND INQUIRY-BASED TEACHING
H. Weller

Inquiry is the broad, complex process by which scientists search for knowledge and understanding of the natural and human-made world. “It 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” (AAAS, 1993, p. 9). Some techniques of inquiry are prediction, question generation, measurement, generation of falsifiable hypotheses, exploration, invention of generalizations, and concept testing by application.

The National Science Education Standards (NRC, 1996) call for teaching students via scientific inquiry: “In the same way that scientists develop their knowledge and understanding as they seek answers to questions about the natural world, students develop an understanding of the natural world when they are actively engaged in scientific inquiry – alone and with others” (p. 29). Science students are not conducting inquiry when they are merely taught about the products of science (facts, concepts, principles, laws, and theories) and about some of the techniques of science, and then only verify some of the products of science.

In COSEE-OS Summer Workshop, science teachers explore many inquiry techniques and their pedagogical foundations. When presented with activities using inexpensive apparatus to apply physical science concepts (e.g., density, pressure, buoyancy, and waves) to the understanding of ocean and climate processes, the teachers generate many of the questions to be investigated and decide how to investigate them. Concurrently, the teachers are introduced to many inquiry-friendly pedagogical techniques (e.g., learning cycle, case study, cooperative learning, triangulation of the assessment of student learning).

References

MOSTLY VERIFICATION OR MOSTLY DISCOVERY?

In the following activities, taken from science and science education textbooks, the students are first told the concept (density or …). Then they are asked to do thinking and actions to verify that concept. How would you alter each of these activities to allow the students to be scientists and discover each concept?

Activity #1 – Density – Grades 5-8

“Which of the grocery bags shown would you rather carry?” [Picture of one grocery bag filled with rolls of paper towels, and an identical grocery bag filled with closed cans of soup.] “These grocery bags are the same size and have equal volume. Both are filled to capacity. The bag of paper towels has much less mass than the bag of cans. The amount of mass an object or material has compared to its volume is a measure of its density. Which has the greater density – the bag of cans or the bag of towels?”

“Density is another physical property used to describe materials. Density is the amount of mass an object or a material has compared to its volume. Density can be expressed as the mass of an object divided by its volume. Recall that grams (g) are the units of mass, and cubic centimeters (cm$^3$) are units of volume. So one way density can be expressed is in grams per cubic centimeter, written g/cm$^3$.

“Suppose two identical bags were tightly closed, and you couldn’t see inside them. Would you be able to tell which bag contained sand and which contained sugar? Surely you could determine the mass of the material in each bag. Perhaps you could guess the volume of each material. But suppose you knew the density of the material in each bag. Would you then be able to tell whether a particular bag contained sand or sugar?

“Because sand and sugar have different densities, you could use this property to tell which material was in each bag. In the activity that follows, you will use density to identify a material.”

Using Density

“In this activity, you will find the density of three materials. You will use this information to help identify an unknown material.

1. Copy the data table into your journal.
2. Use the balance to measure the mass, in grams, of a clean dry graduated cylinder. Record the mass in your table.
3. Fill the cylinder with water to the 50-ml mark.
4. Measure the mass of the filled cylinder and record it in your table under the heading “Total Mass”.
5. Calculate the mass of the water by subtracting the mass of the empty cylinder from the total mass. Record the result under the heading “Actual Mass”.
6. Repeat steps 3-5, first using the salt water, then the rubbing alcohol, and finally the unknown material.
7. Record the data for each material.”

Analyzing

1. “Calculate the density for each material by dividing its actual mass by its volume. Round to two decimal places.
2. Which known material had the highest density?"

Concluding and Applying
3. “What was the unknown material?
4. How did finding the density of the unknown material help you identify it?
5. Going further. What other physical properties might you also look for and measure in identifying materials?"

MAINE LEARNING RESULTS

Density and Buoyancy

E. Structure of Matter
Elementary Grades Pre-K-2
2. Describe some physical properties of objects.
3. Group objects based on observable characteristics (e.g., color, size, texture).

Middle Grades 5-8
1. Predict and test whether objects will float or sink based on a qualitative and quantitative understanding of the concepts of density and buoyancy.

Using Inquiry
J. Inquiry and Problem Solving
Elementary Grades Pre-K-2
2. Ask questions and propose strategies and materials to use in seeking answers to questions.
3. Use results in a purposeful way, which includes making predictions based on patterns they have observed.

Middle Grades 5-8
2. Design and conduct scientific investigations which include controlled experiments and systematic observations. Collect and analyze data, and draw conclusions fairly.
POSSIBLE INQUIRY LESSON PLAN FORMAT

Course__________  Grade/Level_______________  Unit Title______________
Date_____________  Lesson Topic______________________________

Key
Ideas 2.

Cognitive
At the end of the lesson the student will be able to:

Objectives
1. 4.
2. 5.
3. 6.

Affective
At the end of the lesson the student will be able to:

Objectives
1. 3.
2. 4.

Psychomotor
At the end of the lesson the student will be able to:

Objectives
1. 2.

Materials
Text(s)/pp. ______________________________  A.V.__________
Equipment ______________________________
Apparatus ______________________________

Connection to Previous Lesson______________________________

<table>
<thead>
<tr>
<th>Time</th>
<th>Content</th>
<th>Procedures</th>
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<tbody>
<tr>
<td></td>
<td><em>Invitation/Initiation</em></td>
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<td></td>
<td>(“hook”)</td>
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<td></td>
<td><strong>Exploration</strong></td>
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</table>
Invention

Application

Closure

Assessment/Evaluation

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Follow-up of Lesson

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Connection to Next Lesson
EXAMPLE INQUIRY LESSON PLAN
--Introduction to Exploration--

Course Earth Science  Grade/Level K-16 (“recording” of questions and “guidance” varies by grade)

Unit Title Introduction to Inquiry

Date September --, 19--  Lesson Topic Introduction to Exploration

Key
1. Exploration, the first stage of inquiry, involves observing objects (and events) and asking questions as to what puzzles one.
2. In the Exploration stage, the teacher should confine herself or himself to “have you noticed” (attention-calling) questions.

Cognitive Objectives At the end of the lesson the student will be able to:
1. Explore objects and generate her or his own science inquiry questions.
2. Work with fellow students to put their own questions into categories based on similar characteristics.
3. Upon discussion with students in small groups, makes explicit the characteristics used categorize the questions.

Affective Objectives At the end of the lesson the student will be able to:
1. Work in small groups of (4-5 persons).
2. Appreciate and respect each other’s ideas and opinions.
3. Start developing confidence in own ability to observe objects, ask questions, and categorize the questions.

Psychomotor Objectives At the end of the lesson the student will be able to:
None.

Materials Pen/pencil and paper (each student).
Adding machine paper rolls.
Magic markers.
Masking tape on rolls.

Connection to Previous Lesson This is the first lesson in school year. No previous lesson.
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<th>Time</th>
<th>Content</th>
<th>Procedures</th>
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<tr>
<td></td>
<td><strong>Invitation/Initiation</strong>  (“hook”)</td>
<td>1. Ask students to record questions involving the ground, soil, rocks. These can include things connected to the ground (e.g., trees), if the “main” question still involves the ground. (Aides can help record.)</td>
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<tr>
<td>5-10 min.</td>
<td>1. Introduction to forest walk</td>
<td>Tell students whether they should work individually, in pairs or etc.</td>
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<td>Students (or teachers &amp; aides) will carry pads and pens/pencils.</td>
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<td></td>
<td><strong>Exploration</strong></td>
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<td>30-40 min.</td>
<td>2. Forest Walk</td>
<td>2. Students follow teacher through path in forest. They stop and record questions they have during their observations.</td>
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<td>15-20 min.</td>
<td>3. Posting the questions</td>
<td>3. Students return to classroom, sit in small groups (or whole class) and each records 3-5 of his/her “best questions” on separate strips of adding machine paper with magic markers.</td>
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<tr>
<td>15-20 min. 2nd day?</td>
<td>4. Categorizing the questions.</td>
<td>4. Students discuss in small groups (or whole class) which questions to put into similar groups. The questions are taped together into groups.</td>
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<td>5. Students and teacher discuss choices of categories and inclusion of questions in them.</td>
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<td>6. “What we did today is the first stage of science inquiry. It is called “What we did today is the first stage of science inquiry. It is called...”</td>
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</table>
‘Exploration.’ What were the things that we did (i.e., processes) in this stage?

Assessment/Evaluation
Formative evaluation. Teacher observes whether all students understand the categorization and grouping processes.

Follow-up of Lesson
“Please look at the ground and at objects on the ground near your house this afternoon or evening, and think of one more question. Bring this question to class tomorrow.”

Connection to Next Lesson
“Tomorrow we will start thinking about how we will try to find answers to today’s questions. This starts the next stage of science inquiry, called ‘Invention’.”
WHAT IS A UNIT IN SCIENCE TEACHING?
(H. Weller – EDW 472/SMS 491)

A unit is a cluster of several lessons that fit together closely. The lessons of the unit will address the same essential questions and will help the students learn the same enduring understandings.

How many lessons in a unit? There is no set number of lessons in a unit. There could be, say 3, 7, or 10 lessons.

Time span of unit: Several days consecutively, or spread out throughout several other units. Example: A weather unit that involves student collection of weather data over several months.

Example: A unit where the students visit the same portion of land (say, a forest) once or twice each season.

What is a Backwards-Planning Unit?

In backwards-planning, the learning objectives for the unit are decided upon initially. The essential questions and enduring understandings are also decided upon initially. Also, the means by which the instructor will assess the students’ achievement of these objectives are designed initially.

After these decisions are made, the actual lesson activities are designed.

Example: A template for a McTighe-Wiggins backwards-Planning unit will be handed out.
### Unit Cover Page

**Unit Title:**

**Grade Level:**

**Subject Areas:**
- Career Preparation
- English Language Arts
- Health and Physical Education
- Mathematics
- Modern and Classical Languages
- Science and Technology
- Social Studies
- Visual and Performing Arts
- Other:

**Designed by:**

**School District:**

**School:**

**School Address:**

**School Phone:**

**E-Mail Address:**

**Brief Description of Unit:**

**Time Frame:**

**This unit also includes:**
- Learning Results
- Learning Experiences
- Assessments
- Samples of Student Work

Insert here after the cover page a description of the Unit contents (bulleted is fine) and give an overview of the unit. Star (*) the lesson or lessons which you are developing fully.

It would also be good to include key vocabulary words you will be working on in the unit.
### Stage 1: Identifying Desired Results

**Maine Learning Results Content Standards**

<table>
<thead>
<tr>
<th>Content Area:</th>
<th>Content Standards</th>
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</table>

**Enduring Understanding/Essential Questions:**

What key knowledge and skills will students be able to acquire?

<table>
<thead>
<tr>
<th>Students will know:</th>
<th>Students will be able to:</th>
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<tbody>
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</table>

### Stage 2: Assessment Experiences

**Unit title:**

<table>
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<tr>
<th>Developed by:</th>
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**Grade Level:**

<table>
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<tr>
<th>Instructional Activity:</th>
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</table>

**Content Standards Link:**

<table>
<thead>
<tr>
<th>Key Knowledge and Skills Link:</th>
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</table>

**Description of the Assessment Activity:**

<table>
<thead>
<tr>
<th>When is this administered?</th>
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<tbody>
<tr>
<td>Pretest</td>
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</tbody>
</table>
Audience:

Guidelines for Administration:

Allowable Accommodations for Special Needs Students:

Include:

Scoring rubrics
Samples of student work at each performance level

Duplicate as needed if multiple assessment experiences are involved.

Stage 3: Learning Experiences and Instruction

Unit Title:  
Grade Level:  
Curriculum Area:  
Developed by:  

Content Standard(s) Link:
Key Knowledge and Skills Link:

Description of Learning Activity:

Necessary tools/materials:

Resources:
Links to Technology:

Adaptations for Learners with Special Needs:

Extensions/ Challenges:

<table>
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<tr>
<th>Expected Student Products/ Performance (Other than the Assessment)</th>
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<tbody>
<tr>
<td>Written</td>
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Duplicate as needed if multiple learning experiences are involved.

Additional Resources (Optional);
- Reporting forms
- Teacher reflections
- Teacher tips
TEACHING EXPLORATION IN A PRESERVICE SCIENCE COURSE IN MAINE: STUDENTS’ QUESTIONS LEAD THE WAY

By

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Presented at the Annual Conference of the

American Educational Research Association

Montreal, Canada

April 19-23, 1999
TEACHING EXPLORATION IN A PRESERVICE SCIENCE COURSE IN MAINE: STUDENTS’ QUESTIONS LEAD THE WAY

Herman G. Weller
University of Maine

INTRODUCTION: HOLDING MY BREATH DURING A FOREST WALK

Wending their way happily each fall through the patches of afternoon sunlight and shadow among the pines, birches and maple of the Maine woods behind our university campus, my students “listen” to the questions that nature and the physical world ask them, and I hold my breath. It is the introductory lesson for my Studies on the Earth Sciences course, and each September I wonder if it will again be worth the “risk” of letting the students have more control of the discovery portion of their learning. While walking on pine needles and leaping over exposed tree roots, will the students feel the joy that scientists feel during their exploration of an environment, and jot down interesting scientific questions that they “hear” the forest asking them? Or will they ask textbook-type questions that beg for dry, memorized answers?

I set the stage for the walk in the classroom by requesting that when they are in the woods the students let questions come to them that truly interest them. Questions that have intrigued them in the past are fair game also. I try to do this in an attention-getting and slightly humorous fashion. In the classroom, we all close our eyes and “meditate” a little to get into the mood of letting nature’s questions come to us, rather than preparing to seek questions that we think an earth science textbook would ask. Each student is asked to carry a pen or pencil, and a writing pad on the “question walk.” I ask the students to jot down questions during the walk that “relate to the ground,” but each question can also involve such items as vegetation, animals, humans, and weather. For three years, 1995-7, my 20-25 preservice elementary education students have pleasantly surprised me during this discovery jaunt in the forest.

In brief, my research purposes in starting the earth science course with the Forest Question Walk have been to investigate a) how well the topics of the students’ forest questions could match the usual course units, and b) how well the two-day Forest Walk lesson initiates the students’ course involvement with the exploration of earth science. I have discovered that in addition to aspects “a” and “b”, the Forest Walk process has had at least one other beneficial
“side effect” on the course’s teaching and learning processes: it has served as a partial assessment of the students’ prior knowledge which they bring to the course.

Typically, the students jot down wonderful questions that lead very well into the earth science course. The questions asked during the fall 199, 1996, and 1997 forest excursions are shown in the Appendix. For example, the following four questions were among those asked in fall 1997.

1. Why does the soil seem darker and richer in various parts of the forest?
2. Why were the rocks so flat on the trail?
3. Why are there different sizes of rocks?
4. How is the white stripe in a [certain] rock formed?

The first question could lead to an investigation of soil types and the effects on soil of the decomposition of plant matter. The second and third questions could lead to a study of glaciation. The fourth question could lead to an examination of volcanic dikes and sills. The ways that the students’ questions lead into the earth science course are discussed below. First, however, it is interesting to point out that in addition to earth science topics, forest vegetation also plays an important part in many of the students’ questions each fall semester, as shown by the following four examples from fall 1997.

Is moss good for the soil?
Why isn’t the ground level?
Why do tree roots come above the surface, then go below?
How come all the trees and grasses are green?

It is apparent that this same forest walk exercise could be used to lead into a course in biology, botany, or ecology each September. In fact, exploratory question-generation process could probably be used to introduce study in any science discipline. But why should student questions be used to lead into a university science course?
WHY START THE COURSE WITH STUDENT EXPLORATION?

Three experiences in 1994 combined to cause me to implement the question walk introduction to the earth science course. First, on one snowy February weekend in Maine I read Richard Duschl’s (1990) Restructuring Science Education. The following is a typical passage: “The processes of science as portrayed in the majority of elementary and secondary science textbooks have focused almost exclusively on activities associated with the content of testing [or verification]. What results then is an incomplete representation of science” (p. 9). Duschl was referring to the conceptual division of the activity of science into two sets of processes that are equally important in the growth of scientific knowledge: a) the context of discovery, which involves the origin and evolution of ideas; and b) the context of justification, which involves the testing of scientific knowledge claims. Although the view of science that I had developed during several years of biophysics research did not allow me to separate in my mind the contexts of discovery and verification, that wintry weekend I had to admit to myself that our university teaching of science to undergraduates is often as one-sided as Duschl’s description of K-12 science teaching. That is, the science teaching often involves predominantly the context of verification.

Second, on a cool spring morning during an inquiry jog through the forest behind our university campus (Weller, 1998), I resolved to stop teaching the earth science course in a predominantly verifying manner, because I realized that many university scientists and science educators teach science in a totally different manner than we conduct science. In our inquiry we “ask” our own questions; conjecture possible answers or, at least, possible routes of inquiry that might lead to the answers; carry out the testing; and perform any necessary revisions along the way in our questions, routes, or testing” (p. 389). However, too often in our classes in the interest of efficiency and order we “typically present concepts and principles first and then ask our students to verify them with homework problems and laboratory exercises” (p. 389).

In some cases, we may be quite unaware that our course organization results in verification science. For instance, when our course outline states that on Tuesday the students will perform a Boyle’s Law experiment, many grade-conscious students will first check out this law in the textbook to be sure they will have no surprises (and consequently no discovery) in their laboratory data-taking. Often our verification approach is much less subtle: we simply tell the students what they should find. For example, we may announce that “On out Friday field trip
the class will do a transect on a coastal salt march on Smith Neck. We will not the change of vegetation from salt meadow grass and black grass in the high tide zone and, as we move upland, to smooth cordgrass, and then Baltic rush and seaside arrow-grass.” Not only does this make the students’ subsequent investigations rather dull, because they already know the results before starting their observations, it also does not allow them to experience how scientific exploration is conducted.

Third, on a hot and humid day in July, I read chapter 12 of John Dewey’s Democracy and Education (1916) and was surprised to find, almost as far back as the turn of the century, a call for starting a course with student exploration: “the first approach to any subject in school, if thought is to be aroused and not words acquired, should be as unscholastic as possible” (p. 154). A diagnostic question from Dewey (1916, p. 155) helped me realize that in my course I had been trying to motivate my students’ study with “simulated” problems rather than “genuine” problems: “It is the pupil’s own problem, or is it the teacher’s or textbook’s problem, made a problem for the pupil only because he/she cannot get the required mark to be promoted or win the teacher’s approval, unless he/she deals with it?” it occurred to me then that there could be no better introductory approach to my course in the fall than a walk in the Maine woods to “call to mind the sort of situation that presents itself [to out students] outside of school; the sort of occupations that interest and engage activity in ordinary life” (Dewey, 1916, p. 154).

SHOULD EXPLORATION BE TAUGHT IN SCIENCE COURSES?
SOME THOUGHTS FROM THE SCIENCE EDUCATION LITERATURE

What is the author’s bias concerning exploration?

My bias concerning exploration by science students should be put on the table early on. I taught high school science and math for 3 years, conducted biophysics membrane study and research for the next 7 years, and then taught Grades 8-12 science and math for 10 years. When researching the literature for the present study, this mixed background of doing science and teaching science led me to expect many science educators to say that because it is essential for scientists to perform thoughtful exploration in most research endeavors, it is also essential for university students of science to learn how to perform thoughtful exploration. I believed—perhaps incorrectly—that a student at any grade level is to learn the processes of science, then he or she should have practice at carrying out these processes. To paraphrase the
words of some constructivists, I felt that the science student should learn by being a *novice
scientist-epistemologist*. Actually, I have found some support for this belief, in general, in
science education literature for grades PreK-12. However, in the science education literature for
grades PreK-8 there are stronger calls for significant and meaningful student exploration than in
the grade 9-12 literature. The grade 13-16 literature seems to contain even fewer calls for
student exploration during science learning than the grade 9-12 literature.

This idea of a student learning science by acting as a novice scientist-epistemologist does
not seem to me to be an exclusive province of the various types of constructivist schools of
thought of the 1980’s and ‘90s. for example, Bruner (1960, p. 14) certainly seemed to be saying
in 1960 that science students should be novice scientist-epistemologists: “…intellectual activity
anywhere is the same, whether at the frontier of knowledge or in a third-grade classroom. What
a scientist does at his desk or in his laboratory, what a literary critic does in reading a poem, are
the same order as what anybody else does when he is engaged in like activities—if he is to
achieve understanding. The difference is in degree, not in kind. The schoolboy learning physics
is a physicist, and it is easier for him to learn physics behaving like a physicist than doing
something else.”

**What is exploration?**

By exploration in the present study I mean the period of the student’s initial asking of
questions when he or she experiences one or more phenomena of nature or the physical world.
This meaning for exploration is closer the what Hawkins (1974) has called “messing about in
science” than to what Bruner (1961) has termed “discovery,” or what Collette and Chiappetta
(1994) have termed “inquiry.” This meaning for exploration seems to resemble only the very
beginning of what these and other authors have described as the *messing about, discovery, or
inquiry*. Hawkins (1974), writing as a college teacher who had spent two years working in the
Elementary Science Study (ESS) on young children’s learning in science, claimed that in good
science teaching “there is a time, much greater in amount than commonly allowed, which should
be devoted to free and unguided exploratory work (call it play if you wish; I call it work).
Children are given materials and equipment—things—and are allowed to construct, test, probe,
and experiment without superimposed questions or instructions” (p. 67). Hawkins calls this
phase *messing* about.
Karplus, who is usually credited with developing the Learning Cycle model of science instruction has described science teaching as proceeding through active phases of activity, with exploration, invention, and discovering applications (Atkin & Karplus, 1962). Hurd and Gallagher (1968, p. 19) have described exploration as playing a part in the start of Karplus’ Learning Cycle: “As a cycle of lessons begins, children are provided with opportunities for exploring the materials of the lesson so that they get a ‘feel’ for the topic or phenomenon.”

Although the National Science Education Standards (NRC, 1996) do not specifically use the term exploration, their description of inquiry as the “central strategy for teaching science” apparently matches fairly well the present study’s meaning for exploration: “Inquiry into authentic questions generated from student experiences is the central strategy for teaching science. Teachers focus predominantly on real phenomena, in classrooms, outdoors, or in laboratory settings, where students are given investigations or guided toward fashioning investigations that are demanding but within their capabilities” (NRC, 1996, p. 31).

The Benchmarks for Scientific Literacy: Project 2061 of the American Association for the Advancement of Science (1993) do not specifically refer to exploration, either. However, their description of science class inquiry for K-2 students seems to match to some extent the present study’s meaning for exploration (much more than does their descriptions for grade 3-5, 6-8, or 9-12 students): “[K-2] Students should be actively involved in exploring phenomena that interest them both in and out of class. These investigations should be fun and exciting, opening the door to even more things to explore. An important part of the students’ exploration is telling others what they see, what they think, and what it makes them wonder about. Children should have lots of time to talk about what they observe and to compare their observations with those of others” (p. 10).

The present study’s meaning of exploration as the period of the student’s initial asking of questions when experiencing phenomena of the world, most closely matches the question-asking beginning of each unit in the project-based learning environment for 4th and 5th graders described by Galas (1999, p. 11): “Students begin a new area of study by brainstorming ‘wonder’ questions, developing driving questions, and devising their own hypotheses and experiments in a student-centered room design.” After brainstorming questions and then asking 3-5 individual wonder questions, Galas’ students then categorize the questions, in a fashion fairly similar to that of my earth science class: “They discuss [as a class] why a particular category is a good idea and
defend their choice of category before the group with substantive reasons—otherwise the group may not accept the category” (p. 12).

In the State of Maine’s Learning Results (1997, p. 3), the third “Guiding Principle” is aimed at preparing each Maine student to leave school as “A Creative and Practical Problem Solver.” The first part of items “a” and “b” within this guiding principle address student exploration to some extent:

a. [The student] observes situations objectively to clearly and accurately define problems.

b. [The student] frames questions and design data collection and analysis strategies from all disciplines to answer those questions.

In Maine’s Learning Results, under the “Science and Technology” content area, the tenth learning standard, Inquiry and Problem Solving, states that, “Students will apply inquiry and problem solving approaches in science and technology.” Although exploration is not mentioned in this learning standard, the performance indicators that seen to match to some extent the present study’s meaning for exploration are:

Students will be able to…

Pre-K-12

1. Make accurate observations using appropriate tools and units of measure.

Grades 3-4

2. Ask questions and propose strategies and materials to use in seeking answers to questions.

What are scientific discovery and inquiry?

When discussing scientific inquiry, one should probably look back into history at least as far as 1620, when Francis Bacon (1561-1626) published his Novum Organum, in which “…he outlines a ‘new’ scientific method to replace that of Aristotle” (Losee, 1980, p. 61). According to Losee, “…Bacon accepted the main outline of Aristotle’s inductive-deductive theory of scientific procedure. Bacon, like Aristotle, viewed science as a progression from observations to general principles and back to observations” (p. 62).

Likewise, when discussing scientific discovery, one should look back into history at least as far as 1830, when John Herschel (1792-1871) published his Preliminary Discourse on Natural
Philosophy. According to Losee (1980, pp. 115-116), “One of John Herschel’s important contributions to the philosophy of science was a clear distinction between the ‘context of discovery’ and the ‘context of justification.’ He insisted that the procedure used to formulate a theory is strictly irrelevant to the question of its acceptability. A meticulous inductive ascent and a wild guess are on the same footing if their deductive consequences are confirmed by observation. Although he respected Francis Bacon’s views on scientific inquiry, Herschel was aware that many important scientific discoveries do not fit the Baconian pattern. For this reason, he maintained that there are two distinct ways in which a scientist may proceed from observations to laws and theories. One approach is the application of specific inductive schema. The other is the formulation of hypotheses” (Losee, 1980, p. 116).

In general, in the modern science education literature, I have found that the meaning for discovery is more limited in scope than the meaning of inquiry. Bruner (1961) wrote that “…discovery, whether by a schoolboy going it on his own or by a scientist cultivating the growing edge of his field, is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insights” (p. 22).

For Collette and Chiappetta (1994), “generally speaking, inquiry is the process of finding out by searching for knowledge and understanding. Inquiry involves identifying problems, posing questions, and seeking answers” (p. 86). For them, although inquiry is a broader concept than discovery, discovery is apparently a more personal process: “Discovery appears more limited in scope than inquiry, and pertains to the act of figuring out something for oneself—‘Aha, now I’ve got it.’ Science as inquiry contains many elements, some of which do not involve figuring out something for oneself. For example, scientists often call upon others for information to gain greater insight into their pursuits. Although scientists often inquire, they do not often make discoveries” (p. 86).

For Gagne’ in 1993, inquiry was also a broader, more complex, process than discovery, and was learned as the culmination of learning by many small steps of discovery: “But discovery, as a very fundamental condition of most learning, should not be equated with enquiry, which is the exercise of all the various activities making up what we have identified as the terminal capability [the desired student ability to use the inquiry approach for the solution of problems]. The construction of a response by a learner, something that happens nearly every
step of the way in the process of learning, is what usually has been called discovery. In contrast to this, enquiry is the terminal thinking process we want the student to be able to engage in, after he has taken all the necessary previous steps in learning” (Gagne, 1963, p. 149).

Karplus provided a somewhat different meaning for discovery, during his co-leadership with Steiner of the preparation of the upper grade physical science lessons for the Science Curriculum Improvements Study (SCIS) in the 1960s. Karplus wrote, contrasting a conceptual invention lesson with a concept application lesson: “To contrast those lessons in which a new concept is introduced with those in which a concept is applied to new experiences, we use the words invention and discovery. In our meaning, a conceptual invention is a new idea for interpreting experience, an idea which resulted from an inductive mental leap. A discovery is the recognition of a relationship between an idea and an observation, or between two ideas, or between two observations. A lesson in which a new concept is introduced may therefore be called an invention lesson, while the application of the application of the concept gives rise to discovery lessons” (Karplus & Their, 1967, p. 40).

In general, the National Science Education Standards (NRC, 1996) science teaching standards call for the teaching of students science via scientific inquiry: “In the same way that scientists develop their knowledge and understanding as they seek answers to questions about the natural world, students develop an understanding of the natural world when they are actively engaged in scientific inquiry—alone and with others” (p. 29).

The Benchmarks for Scientific Literacy: Project 2061 of the American Association for the Advancement of Science (1993) warn that scientific inquiry is far from the rigid “scientific method” that has been commonly depicted in textbooks: “Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naïve idea of ‘making a great many careful observations and then organizing them.’ It 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” (AAAS, 1993, p. 9).

The Project 2061 Benchmarks (AAAS, 1993) also point out that authentic scientific investigations should be far different than the usually high school science “experiment”: “If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonable accurate. But that will
require recasting typical laboratory work. The usual high school science ‘experiment’ is unlike the real thing: The question to be investigated is decided by the teacher, not the investigators; what apparatus to use, what data to collect, and how to organize the data are also decided by the teacher (or the lab manual); time is not made available for repetitions or, when things are not working out, for revising the experiment; the results are not presented to other investigators for criticism; and, to top it off, the correct answer is known ahead of time” (p. 9). Unfortunately, this description of a high school “experiment” could apply equally to many university undergraduate science investigations.

The Benchmarks (AAAS, 1993, p. 9) propose that, in contrast, to such “experiments, “Such investigations should become more ambitious and more sophisticated. Before graduating from high school, students working individually or in groups should design and carry out at least one major investigation. They should frame the question, design the approach, estimate the time and costs involved, calibrate the instruments, conduct trial runs, write a report, and finally, respond to criticism.”

In Maine Learning Results, under the “Science and Technology” content area, the tenth learning standard, Inquiry and Problem Solving, states that “Students will apply inquiry and problem solving approaches in science and technology.” The following three performance indicators clarify the operational meaning of “inquiry and problem solving” used here fairly well:

Students will be able to…

Grades 3-4
3. Ask questions and propose strategies and materials to use in seeking answers to questions.

PreK-12
1. Make accurate observations using appropriate tools and units of measure.

Middle Grades 5-8
2. Design and conduct scientific investigations which include controlled experiments and systematic observations. Collect and analyze data, and draw conclusions fairly.

Secondary Grades
3. Verify, evaluate, and use results in a purposeful way. This includes analyzing and interpreting data, making predictions based on observed patterns, testing solutions against the original problem conditions, and formulating additional questions.

**How can a teacher foster student exploration in science teaching?**

To encourage the generation of spontaneous questions during the Forest Walk in the earth science course, I exposed the students to an object-rich environment, a forest, and used a bare minimum of teacher direction. This objects-exposure approach was parallel to an elementary school approach intended to elicit questioning from young children. Jelly (1985, p. 50) has described this approach:

“If questioning styles are not taught, a teacher’s verbal questioning will probably be the most important factor in establishing a climate conducive to question-asking by children. But it is not the only factor and so it is useful to consider ways by which curiosity might be aroused and how such curiosity can be linked to particular questioning frameworks. As a first step we need to get children’s interest stimulated and this means giving them direct contact with materials. It also means that we need to think carefully about the nature of the materials that make children curious. Materials brought in spontaneously by the children have a built-in curiosity factor and need no further discussion; but what of materials selected by teachers? These can usefully be considered in two categories: those with immediate appeal and those that are commonplace when seen through childs’ eyes, but which can evoke curiosity if teacher tactics present hem in a new and challenging light.”

For the Forest Walk, the materials selected by the teacher were all the living and non-living aspects of the forest. I tried to present these materials to my students in a new and challenging light by encouraging them to let questions come to them that truly interested them.

**THE STUDENTS AND THE COURSE**

Two external considerations have influenced my general approach to the Earth Science course a great deal. First, 60-70% of the course participants take only 2-3 science course in their
undergraduate careers. The other university science course or courses they take are commonly introductory-level survey course that cover quite rapidly a plethora of the results of science (concepts, principles and laws), touch only lightly on the processes of science, and persuade many of my Earth Science students that they cannot do science very well. To balance this effect, I spend most of the earth science course on hands-on experiences for the students, designed to persuade the students that they can do science and they can teach science. Second, many of the elementary and middle schools in which the course participants will teach do not have much equipment and materials for teaching science. So I use mostly inexpensive equipment and materials in the course. However, until the implementation of the forest exploration lesson in 1995, the Earth Science lessons involved mostly the context of verification; the students were involved only in a modicum of the context of discovery.

THE EXPLORATION LESSON: BASIC OUTLINE
   The Introduction to Exploration lesson is summarized in Table 1.

<table>
<thead>
<tr>
<th>Session</th>
<th>Location</th>
<th>Day</th>
<th>Time (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction to forest walk</td>
<td>Classroom</td>
<td>1</td>
<td>5 – 10</td>
</tr>
<tr>
<td>2. Forest “question walk”</td>
<td>Forest</td>
<td>1</td>
<td>30 – 40</td>
</tr>
<tr>
<td>3. Posting the questions</td>
<td>Classroom</td>
<td>1</td>
<td>20 – 25</td>
</tr>
<tr>
<td>4. Categorizing the questions</td>
<td>Classroom</td>
<td>2</td>
<td>20 – 25</td>
</tr>
<tr>
<td>5. Discussion of the categories</td>
<td>Classroom</td>
<td>2</td>
<td>15 – 20</td>
</tr>
<tr>
<td>6. Closure</td>
<td>Classroom</td>
<td>2</td>
<td>5 – 10</td>
</tr>
</tbody>
</table>

OBJECTIVES OF THE EXPLORATION LESSON
   The intellectual (cognitive) objectives of the exploration lesson were to enable each student to:

   1. Explore “ground-related” objects and organisms of the forest and generate his or her own science inquiry questions.
   2. Work with fellow students in small groups to put the questions into categories based on similar characteristics.
   3. Work with fellow students in small groups to make explicit the characteristics used to categorize the questions.
Whether explicit or implicit, at the college level each lesson or unit has social and emotional objectives. The earth science course includes many laboratory experiences in small groups, in which the students act in various roles as novice scientists. Therefore, for the exploration lesson, the social and emotional objectives are to enable each student to:

1. Improve his or her ability to work in a small group (4-5 persons).
2. Improve his or her appreciation and respect each other’s ideas and opinions.
3. Improve confidence in own ability to observe objects, ask questions, and categorize the questions.

WHAT LEARNING EXPERIENCES ARE ASSOCIATED WITH THE FOREST WALK?

Each September when the earth science returns from the forest to the classroom, the students each record their 3-5 best questions with magic marker on paper adding-machine tape, and taped them up on the whiteboards and bulletin boards, so that we could start appreciating many of our questions and wondering about grouping them. For the next class period, I word-processed all the questions, and handed them out to each small group (4-5 students) for processing. Each small group first looked for similar or identical questions, and merged them to form fewer questions. Next each team grouped the questions into 4-6 categories and named each category. Finally, a representative from each team explained to the whole class the reason for the team’s questions categories.

For closure, I asked the class to describe the ways that they believed that their question-generation process resembled what scientists do during exploration. If, during the discussion, no student brought up the fact that finding categories of organisms, objects, or events is the way that scientists create concepts, I introduce this idea and we talk about that.

Each fall following this lesson, each student has chosen 2-3 of the questions (the number has depended on the specific semester) for which he or she will pursue answers. Their answers are due at mid-semester, but often their knowledge has led to important input when related topics have arisen in the course.
What do students do who cannot walk to and through the forest?

Before the Forest Walk, I ask any students who are unable to walk to and through the forest if they feel that they can remain in the classroom, imagine walking through the forest, and generate 3-5 questions generated spontaneously during their imaginary walk. In the three years of the Forest Walk, the one or two students each semester who have done this have been able to brainstorm questions quite well.

RESULTS AND DISCUSSION

The first research purpose was to determine how well the students’ Forest Walk questions could match the usual course units. All the student questions for the exploration lesson in the fall 1995, 1996, and 1997 semesters are shown in the Appendix. The usual course units are shown in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Usual course units in earth science course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
</tr>
<tr>
<td>Including <em>Forest Walk</em> lesson</td>
</tr>
<tr>
<td>Properties of rocks</td>
</tr>
<tr>
<td>Rock Cycle</td>
</tr>
<tr>
<td>Igneous Rocks</td>
</tr>
<tr>
<td>Sedimentary Rocks</td>
</tr>
<tr>
<td>Metamorphic Rocks</td>
</tr>
<tr>
<td>Weathering/soil</td>
</tr>
<tr>
<td>Glaciation</td>
</tr>
<tr>
<td>Earthquakes</td>
</tr>
<tr>
<td>Earth’s internal structure</td>
</tr>
<tr>
<td>Plate tectonics</td>
</tr>
</tbody>
</table>

The course is taught and learned predominantly in a student hands-on manner, with students conducting hands-on inquiry nearly every class period. Due to time constraints, some units that typically occur in an earth science course are missing (e.g., Deserts, Mass Wasting, Hydrologic Cycle, Oceans, Mountain building, Atmosphere, Air Pressure and Wind). Some aspects of each of these units do occur within the course units (Table 2). Astronomy units, which are often taught in an earth science course, are taught in a second earth science course.
Categories of questions (student-created)

The categories in which the students grouped their questions for the forest question walks for 1995, 1996, and 1997 are shown in Table 3.

Table 3
Student categories for their questions with the number of student questions for each category, 1995-97

<table>
<thead>
<tr>
<th></th>
<th>Fall 1995</th>
<th>Fall 1996</th>
<th>Fall 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocks</td>
<td>(9)</td>
<td>(17)</td>
<td>(29)</td>
</tr>
<tr>
<td>Soil/ground</td>
<td>(11)</td>
<td>(2)</td>
<td>(11)</td>
</tr>
<tr>
<td>Trees</td>
<td>(14)</td>
<td>....</td>
<td>Trees/Roots (16)</td>
</tr>
<tr>
<td>Leaves</td>
<td>(6)</td>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>Plants</td>
<td>(2)</td>
<td>Plants (6)</td>
<td>other vegetation [than trees] (11)</td>
</tr>
<tr>
<td>Grass</td>
<td>(3)</td>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>Moss</td>
<td>(3)</td>
<td>....</td>
<td>....</td>
</tr>
</tbody>
</table>

Subcategories (instructor-created) of questions, matched with usual course units

To investigate the match of the students’ Forest Walk questions with the usual units of the earth science course, I have created subcategories for the questions in all of the students’ categories (Table 4A – 4H). Tables 4A – 4H also show for the questions on each subcategory the percentage of all the questions for each year. Usual course units are shown (at right) in Table 4A – 4H in which each subcategory could fit.

Table 4A
Comparison of instructor-created subcategories for students’ questions with course units, for the student Rocks category, 1995-97

<table>
<thead>
<tr>
<th>Subcategories of questions</th>
<th>% of all questions for each year 1995 1996 1997</th>
<th>Usual course units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock surface texture</td>
<td>2 19 0</td>
<td>Properties of rocks</td>
</tr>
<tr>
<td>Rock surface color</td>
<td>2 8 3</td>
<td>Properties of rocks</td>
</tr>
<tr>
<td>Rock shape</td>
<td>0 12 0</td>
<td>Properties of rocks</td>
</tr>
<tr>
<td>Rock composition</td>
<td>0 0 1</td>
<td>Properties of rocks</td>
</tr>
<tr>
<td>Exposed bedrock/</td>
<td>9 4 19</td>
<td>Glaciation</td>
</tr>
<tr>
<td>Glaciation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock creation</td>
<td>4 0 7</td>
<td>Rock cycle</td>
</tr>
<tr>
<td>Volcanic intrusion</td>
<td>2 8 3</td>
<td>Volcanic rocks</td>
</tr>
<tr>
<td>Weathering/Erosion</td>
<td>0 4 1</td>
<td>Weathering/Soil</td>
</tr>
<tr>
<td>Rock-Soil interaction</td>
<td>0 4 3</td>
<td>Weathering/Soil</td>
</tr>
<tr>
<td>Human influence on rocks</td>
<td>0 8 4</td>
<td>Human impact on the environment</td>
</tr>
</tbody>
</table>
### Table 4B
Comparison of instructor-created subcategories for students’ questions with course units, for the student **Soil/ground** category, 1995-97

<table>
<thead>
<tr>
<th>Subcategories of questions</th>
<th>% of all questions for each year</th>
<th>Usual course units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil creation/Erosion/Decay</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Soil composition</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Rock-soil interaction</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Land topography</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Soil-vegetation interaction</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Soil Coarseness, porosity, and absorption</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 4C
Comparison of instructor-created subcategories for students’ questions with course units, for the student **Trees** category, 1995-97

<table>
<thead>
<tr>
<th>Subcategories of questions</th>
<th>% of all questions for each year</th>
<th>Usual course units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree growth</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tree roots</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Uprooting of trees</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Individual differences between trees</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Death/decay of branches &amp; trees</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
### Table 4D
Comparison of instructor-created subcategories for students’ questions with course units, for the student **Leaves** category, 1995-97

<table>
<thead>
<tr>
<th>Subcategories of questions</th>
<th>% of all questions for each year</th>
<th>Usual course units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf variety and color</td>
<td>13</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 4E
Comparison of instructor-created subcategories for students’ questions with course units, for the student **Plants** category, 1995-97

<table>
<thead>
<tr>
<th>Subcategories of questions</th>
<th>% of all questions for each year</th>
<th>Usual course units</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Soil-vegetation-sunlight-rainwater interaction</em></td>
<td>4</td>
<td>23</td>
</tr>
</tbody>
</table>

### Table 4F
Comparison of instructor-created subcategories for students’ questions with course units, for the student **Grass** category, 1995-97

<table>
<thead>
<tr>
<th>Subcategories of questions</th>
<th>% of all questions for each year</th>
<th>Usual course units</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Soil-vegetation-sunlight-rainwater interaction</em></td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 4G
Comparison of instructor-created subcategories for students’ questions with course units, for the student **Moss** category, 1995-97

<table>
<thead>
<tr>
<th>Subcategories of questions</th>
<th>% of all questions for each year</th>
<th>Usual course units</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Soil-vegetation-rainwater interaction</em></td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 4H
Comparison of instructor-created subcategories for students’ questions with course units, for the student Other vegetation (than trees) category, 1995-97

<table>
<thead>
<tr>
<th>Subcategories of questions</th>
<th>% of all questions for each year</th>
<th>Usual course units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil-vegetation-rainwater interaction</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

How well did the Forest Walk begin the students’ involvement in exploration in the course?

The second research purpose was to investigate how well the Forest Question Walk lesson begins the students’ course involvement in the exploration of earth science. The Forest Walk seemed to “set the pace” for the rest of the course. From that point on the students showed that they understood that science can be fun. They showed that they expected exploration to be a component of their daily investigations. They seemed to be more open than in preceding years to develop several of their own questions during these explorations. The Forest Walk lesson seemed, also, to “open the door” during the rest of each semester in general to the students’ generation and of their own questions and their trusting of their ability to do so.

Specifically, the author has observed the following student benefits to have occurred due to the Forest Walk: a) Each year the students have learned to ask and trust their own genuine questions in science. b) They have learned how to combine and categorize questions. c) They have had fun and have become intrigued by their questions. d) They have developed a sense of what scientists do during exploration. e) In the follow-up phase, pursuing answers to student questions and inventing reasonable answers, they have been (for the most part) happy and interested—emotions that the majority have carried on into the remainder of the course.

The Forest Walk as a partial assessment of the students’ prior knowledge

There was not much evidence of non-canonical scientific beliefs in the students’ Forest walk questions that involved earth science. However, both the students’ Forest Walk questions and their categorizations of the questions involving biological science highlighted some non-canonical beliefs of at least some of the students. For example, the question in fall 1995 “How do plants grow out of dead wood?” showed that the asker did not classify fungi as non-plants, as scientists do. As another example, their classification in fall 1995 of questions involving Leaves,
Grass, and Moss as separate from Plants, showed that at least on small group did not classify leaves, grass, and moss as plants, as scientists do.

**The students’ follow-up modes of investigation to answer their forest Walk questions**

Although it was not directly a research purpose of this study to investigate the ways in which the students found answers to their Forest Walk questions, this answering process also helped “set the pace” for the rest of the course. Each student chose 2-3 Forest Walk questions to answer during the semester. As each student endeavored during the semester to answer the 2-3 questions that he or she had chosen, the following modes of investigation were employed: a) ask a science expert, b) revisit the forest, c) consult the Internet, d) consult textbook/ reference books, e) discuss with other students, f) create a simulation of the questions-raising situation.

**CONCLUSION**

**Science content**

Each year the students’ categories for their Forest Walk questions have fit fairly well into the usual course units of Properties of Rocks, Glaciation, Weathering/Soil, and Rock Cycle, as have the instructor-created subcategories. The students’ questions and instructor’s subcategories have also served as a component of the assessment of the student’s prior knowledge of these aspects of earth science. In years 1995-1997, most of the students’ non-canonical beliefs have occurred in the areas of biology, rather than earth science. This has allowed the instructor to look for possible knowledge gaps and alternative conceptions/frameworks that the students may possess.

**Students and science processes**

The Forest Walk has contributed as follows to the development of the students’ understanding and use of science processes:

1. Each year the Forest Walk has successfully started most of the earth science students on the road to asking and trusting their own genuine questions in science.
2. The students have learned how to combine and categorize questions, a first step toward learning to categorize data in science to create concepts.
3. The students have had fun and have become intrigued by their questions.
4. The students have developed a sense of what scientists do during exploration.
5. While pursuing answers to their Forest walk questions in the follow-up phase, the students have been for the most part happy and interested, emotions that the majority have carried on into the remainder of the course.

REFERENCES


## APPENDIX

### Comparison of student questions from 1995, 1996, and 1997

<table>
<thead>
<tr>
<th>Rocks</th>
<th>Fall 1995</th>
<th>Fall 1996</th>
<th>Fall 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock surface texture</td>
<td>Why are some rocks smooth, while others are coarse and rough?</td>
<td>Why are some rocks smooth and others rough?</td>
<td>Why are some rocks smooth?</td>
</tr>
<tr>
<td></td>
<td>Why do the rocks have different textures?</td>
<td>Why are some rocks shiny and others dull?</td>
<td>Why are some rocks flat and why are some really bumpy?</td>
</tr>
<tr>
<td>Rock surface color</td>
<td>Why are the rocks different colors?</td>
<td>What accounts for the color variations (light gray, dark gray, brown) in various rocks?</td>
<td>Why are there different colors of rocks?</td>
</tr>
<tr>
<td></td>
<td>Why are some rocks red?</td>
<td>Why are some rocks red?</td>
<td>What type of rock is orange In color?</td>
</tr>
<tr>
<td>Rock shape</td>
<td>Why do some rocks have straight edges or corners?</td>
<td>Why do some rocks have straight edges or corners?</td>
<td>What type of rock is orange In color?</td>
</tr>
<tr>
<td></td>
<td>What causes the rocks to be cut at different angles?</td>
<td>What causes the rocks to be cut at different angles?</td>
<td>What type of rock is orange In color?</td>
</tr>
<tr>
<td></td>
<td>Are the smaller rocks pieces of the bigger rocks, just broken off?</td>
<td>Are the smaller rocks pieces of the bigger rocks, just broken off?</td>
<td>What type of rock is orange In color?</td>
</tr>
<tr>
<td>Rock composition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposed bedrock/ Glaciation</td>
<td>How come rocks of various sizes are found in the same area?</td>
<td>Why are the rocks that come out of the road almost always flat on top?</td>
<td>Why were the rocks so flat on the trail?</td>
</tr>
<tr>
<td>Why are there ledges in the middle of the woods?</td>
<td></td>
<td>Why were the rocks so flat on the trail?</td>
<td>What are the flat rocks?</td>
</tr>
<tr>
<td>How far does the ledge go beneath the soil?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Why do some areas have more rocks than others?</td>
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<tr>
<td>How come so many different types of rocks can be found so close together?</td>
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<tr>
<td>Was a [certain] big rock made of quartz?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Why was there so much ledge?</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Why was the ledge so smooth?
Are the cuts on some rocks striations from glaciers?
Why are there different sizes of rocks?
How did all the large rocks get where they are?
Why are there so many different types of rocks?
As we walked through the forest, we came upon large pieces of rock coming out of the ground. Why were they there? What geological forces put them there? Why are they not buried, so that we can see them?
Where did these rocks [along the path/road] originate? What place? What geological era?
Was this rock [beside the path/road] once a mountain, or part of a mountain?
How old were the rocks that we could see as we walked along the trails, and what [geological] period did they originate from?
How do rocks form in the middle of the woods?
What is the major rock composition in Maine?
What types of rocks were the ones that we could see as we walked along the trails? Were any of the sedimentary, igneous, or metamorphic in their origin?
How do you determine how old certain rocks are?
How many geological eras can be traced in a one-inch high rock?

Rock creation?
Where do rocks come from?
What kind of rock is most common in this area?
<table>
<thead>
<tr>
<th>Fall 1995</th>
<th>Fall 1996</th>
<th>Fall 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volcanic Intrusion</strong></td>
<td>Why do some rocks have stripes or spots?</td>
<td>Why are some rocks gray with white stripes through them?</td>
</tr>
<tr>
<td></td>
<td>Why are some rocks gray with white stripes through them?</td>
<td>Why is there sometimes a white line (or layer) all the way through a dark rock?</td>
</tr>
<tr>
<td><strong>Weathering/ Erosion</strong></td>
<td>Is gravel made up of rocks?</td>
<td>What causes the splitting and cracking of rocks?</td>
</tr>
<tr>
<td><strong>Interaction between soil and rocks</strong></td>
<td>Why do some rocks poke out of the ground more than others?</td>
<td>Why was only a portion of [a certain] big rock exposed?</td>
</tr>
<tr>
<td><strong>Human influence</strong></td>
<td>Why are the rocks neatly lines up around the paths?</td>
<td>How did tar get on the dirt road in the middle of the woods?</td>
</tr>
<tr>
<td><strong>Soil/ground</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Soil/creation/erosion/decay</strong></td>
<td>Why isn’t the ground level?</td>
<td>Why does erosion occur? (Patches of ground rise above other patches.)</td>
</tr>
<tr>
<td></td>
<td>Do dead trees turn to dirt?</td>
<td>Why does this occur more often near the road?</td>
</tr>
<tr>
<td></td>
<td>Why was there a hole in the ground without a stump (from the tree that used to be there?)?</td>
<td>How fast do the pine needles on the soil decompose?</td>
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<tr>
<td></td>
<td>Part of the ground felt like it was a sinkhole—not mud, but a hole. Why?</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>How deep is the pine needle cover on the ground?</td>
</tr>
<tr>
<td>Fall 1995</td>
<td>Fall 1996</td>
<td>Fall 1997</td>
</tr>
<tr>
<td>-----------------------------------</td>
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</tr>
<tr>
<td><strong>Soil composition</strong></td>
<td><strong>What makes soil dark?</strong></td>
<td><strong>Why does the soil seem darker and richer in various parts of the forest?</strong></td>
</tr>
<tr>
<td>Some soils are different colors.</td>
<td>Why is the ground so soft?</td>
<td></td>
</tr>
<tr>
<td><strong>Why is some soil soft,</strong></td>
<td>Why does soil’s appearance change from within the forest area to the open space? Does it have to do with the light?</td>
<td></td>
</tr>
<tr>
<td><strong>Rock-soil interaction</strong></td>
<td></td>
<td><strong>How is the soil affected by large rocks?</strong></td>
</tr>
<tr>
<td>What’s under dirt?</td>
<td></td>
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<tr>
<td><strong>Land topography</strong></td>
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<tr>
<td><strong>Soil-vegetation interaction</strong></td>
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</tr>
<tr>
<td><strong>Soil coarseness, porosity, and</strong></td>
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<tr>
<td><strong>water absorption</strong></td>
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<td></td>
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<tr>
<td><strong>Trees</strong></td>
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<tr>
<td><strong>Trees growth</strong></td>
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</tbody>
</table>

**Why do some of the roots grow above the ground?**
[seeking oxygen?]
<table>
<thead>
<tr>
<th>Fall 1995</th>
<th>Fall 1996</th>
<th>Fall 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Root-soil interaction</strong>&lt;br&gt;Are the roots in the ground alive?</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Why does new growth [of grass, bushes, trees] occur in the shady, dark parts beneath the higher, light-absorbing trees? Don’t the taller trees absorb the light?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Are green acorns “not ready,” or are they “over ready?”</td>
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<tr>
<td></td>
<td></td>
<td>Approximately what percent of the fallen acorns grow into trees?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Where are all the pinecones? E.g., I saw “tons of” pine needles, but only one cone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If a tree grows taller, do its roots grow deeper?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why does each different type of tree grow only to a certain height?</td>
</tr>
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<td></td>
<td></td>
<td>How deep do most roots go?</td>
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<tr>
<td></td>
<td></td>
<td>Why do roots come out of the surface, then go below?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why do some of the roots grow above the ground?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why do the roots come out of the ground instead of going down [into the ground?]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why are the roots of trees exposed far away from the tree itself?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does it hurt the trees when their roots are exposed?</td>
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<tr>
<td></td>
<td></td>
<td>Do most trees fall down by themselves, or do human beings help them?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why do the roots come out of the ground instead of going down [into the ground?]</td>
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<td>Why are the roots of trees exposed far away from the tree itself?</td>
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<td></td>
<td></td>
<td>Does it hurt the trees when their roots are exposed?</td>
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<tr>
<td></td>
<td></td>
<td>Do most trees fall down by themselves, or do human beings help them?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why do the roots come out of the ground instead of going down [into the ground?]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why are the roots of trees exposed far away from the tree itself?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does it hurt the trees when their roots are exposed?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Do most trees fall down by themselves, or do human beings help them?</td>
</tr>
</tbody>
</table>
Fall 1995

Why would anyone want to ruin a beautiful forest and cut down trees to make a bike path?

Individual differences between trees
Why do some trees have the same base?
Why are some trees skinny and others fat?
Why is some bark smooth, and some bark rough?
Why is the bark different on trees—color, texture, etc.?

“Death” of branches, trees
Once a tree dies, how long does it take for the roots to go in the ground?
Why do trees rot 3 or 4 feet above the ground?
Why are there some “evergreen” trees that are totally green, but have a few branches that are dead?

Miscellaneous
If a tree falls in the woods and nobody is there, does it make a sound?

Leaves
Leaf variety and color
Why are there so many dead leaves on the ground?
Why are there so many different leaves in one area?
Why are there so few red leaves?
Why are the leaves different colors?
Why are the back sides of some green leaves white?

Fall 1996

Are the trees being uprooted because they are so close to the trail?
Why do the bases of trees come out of the ground on the sides of the roads?
<table>
<thead>
<tr>
<th>Fall 1995</th>
<th>Fall 1996</th>
<th>Fall 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why are there so many pine needles on the ground?</td>
<td>Why do certain plants/flowers grow in certain areas?</td>
<td>Why do certain plants/flowers grow in certain areas?</td>
</tr>
<tr>
<td><strong>Plants</strong></td>
<td>Why do only ferns grow on the road and not trees?</td>
<td>Why do only ferns grow on the road and not trees?</td>
</tr>
<tr>
<td>How can weeds grow in dirt?</td>
<td>Why do trees not grow straight?</td>
<td>Why do trees not grow straight?</td>
</tr>
<tr>
<td></td>
<td>Why does moss grow on rocks?</td>
<td>Why does moss grow on rocks?</td>
</tr>
<tr>
<td></td>
<td>Why do rocks in the woods have moss, and rocks on or by the trail do not have moss?</td>
<td>Why do rocks in the woods have moss, and rocks on or by the trail do not have moss?</td>
</tr>
<tr>
<td><strong>Grass</strong></td>
<td>Why doesn’t grass grow at the bases of trees?</td>
<td>Why does new growth [of grass, bushes, tress] occur in the shady, dark parts beneath the taller, light-absorbing tress?</td>
</tr>
<tr>
<td>Soil-vegetation-sunlight-rainwater interaction</td>
<td>Why does grass stop growing at the edge of the woods?</td>
<td>Don’t the taller trees absorb the light?</td>
</tr>
<tr>
<td>Why does the grass grow only on the edges of the path?</td>
<td>Why does the grass in the fields grow only to a certain height?</td>
<td>Can grass grow through the cracks in the path?</td>
</tr>
<tr>
<td><strong>Other vegetation than trees?</strong></td>
<td>How come all the trees and grasses are green?</td>
<td>Why does the grass in the fields grow only to a certain height?</td>
</tr>
</tbody>
</table>
How did that patch of wild-flowers get there? How did the seeds get spread there, when there are no other patches of flowers in sight?

What is the most common plant found in the woods?

What was that orange mushroom-type thing?

What type of soil do mushrooms “like to” grow in?

When humans created the roads and trails through the forest, what effect did this have on that environment? Did it affect the organisms living there?

If humans got rid of all, or some of, the vegetation in that area, what effect would it have on the land features there?

Why does moss grow on rocks?

Does moss grow from the ground up?

Is moss good for the soil? (2nd category for this one)

Why is there moss on only some of the rocks?

How come most of the moss on trees is found on the bottom of their trunks?
THE NATURE OF SCIENCE


A. The following statements are about what science is and how it works.

Instructions: a) Please indicate whether each of the following statements about the nature of science is True or False. b) For each item that you indicate as False, please write briefly your reason(s) for it being False.

1. _____ (T or F) **Hypotheses become theories which become laws.**

2. _____ (T or F) **A hypothesis is an educated guess.**

3. _____ (T or F) **A general and universal scientific method exists.**

4. _____ (T or F) **Evidence accumulated carefully will result in sure knowledge.**

5. _____ (T or F) **Science and its methods provide absolute proof.**

6. _____ (T or F) **Science is procedural more than creative.**

7. _____ (T or F) **Science and its methods can answer all questions.**

8. _____ (T or F) **Scientists are particularly objective.**

9. _____ (T or F) **Experiments are the principle route to scientific knowledge.**

10. _____ (T or F) **All work in science is reviewed to keep the process honest.**
B. The following statements are about what science is and how it works.

Instructions: a) For each of the alternatives, A-E, check the box that best indicates your belief about the alternatives. b) If you have an answer for a question that is different than any of the answers given, please write it as an alternative F. c) Explain your answers to each question briefly below the table of alternatives.

11. How many confirming experiments (observations) do you think are needed to prove a scientific theory beyond doubt?

a. None. Scientific theories are based on evidence and therefore are true descriptions of what exists.

b. Theories cannot be proven beyond doubt.

c. One. Once shown to be correct, there is no need for further experiment.

d. About 10 to 100, depending on whose theory it is.

e. At least 1,000,000.

f. Your answer (if different from those above):

Table for your answers for #11

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitely a correct answer</td>
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<tr>
<td>Probably a correct answer</td>
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<tr>
<td>Maybe a correct answer</td>
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<tr>
<td>Probably not a correct answer</td>
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<tr>
<td>Definitely not a correct answer</td>
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</table>

Write a paragraph explaining the answers you gave in the table above.
11. This is a true story. Using Newton’s laws of gravitation, a French scientist found that the predicted path of the planet Uranus was slightly different from its observed path. To explain the difference, again using Newton’s laws, he predicted there must be another planet farther from the sun than Uranus. He predicted the mass of the planet and its path. The same year, a German scientist, guided by the prediction, and using a very powerful telescope, found a planet just where it was predicted to be.

The observed path of the planet Mercury is also a bit different from its Newtonian predicted path. The same French scientist, again using Newton’s laws predicted the difference could be explained by the existence of a small planet between Mercury and the sun. He called the little planet Vulcan. But Vulcan has never been found, even though many scientists have sought for it.

Which of the following sets of statements do you think provides the best scientific understanding of the story, and its continuation?

a. Newton’s law of gravitation is based on a lot of evidence and is a true description of what exists, therefore Vulcan will eventually be found.

b. Vulcan does not exist. Newton’s law of gravitation has been shown to be limited but should be retained to provide useful approximations.

c. Vulcan does not exist. Newton’s law of gravitation has been shown to be wrong and should be discarded.

d. Newton’s law of gravitation was proved correct by the discovery of Neptune just as predicted, therefore Vulcan will eventually be found.

e. Newton’s law of gravitation appeared limited and approximate, but should be retained until a better law is invented.

f. Your answer (if different from those above):

<table>
<thead>
<tr>
<th>Table for your answers for #12</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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<td>-----------------------------</td>
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<tr>
<td>Definitely a correct answer</td>
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<tr>
<td>Probably a correct answer</td>
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<tr>
<td>Maybe a correct answer</td>
</tr>
<tr>
<td>Probably not a correct answer</td>
</tr>
<tr>
<td>Definitely not a correct answer</td>
</tr>
</tbody>
</table>

Write a paragraph explaining the answers you gave in the table.
13. How many disconfirming experiments (observations) do you think are needed to disprove a scientific theory beyond doubt?

A. None. Although scientific laws take known data into account, they are mental inventions and are undoubtedly false in any exact sense.
B. One. If a deduction from a theory is shown to be wrong by means of experiment, then the theory is false.
C. About 10 to 100, depending on whose theory it is.
D. It is impossible in practice to disprove a theory beyond doubt, because experiment testing involves other theories, and it may be these which are false.
E. The number of disconfirmations is important in that one theory may be superseded by another that can solve more problems and doesn’t have as many anomalies.
F. Your answer (if different from those above):

Table for your answers for #13

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
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<tbody>
<tr>
<td>Definitely a correct answer</td>
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<tr>
<td>Probably a correct answer</td>
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<tr>
<td>Maybe a correct answer</td>
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<tr>
<td>Probably not a correct answer</td>
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<tr>
<td>Definitely not a correct answer</td>
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</tbody>
</table>

Write a paragraph explaining the answers you gave in the table above.
A. The following statements are about inquiry-based learning and teaching of science.

Instructions: a) Please indicate whether each of the following statements is True or False. b) For each item that you indicate as False, please write briefly your reason(s) for it being false.

1. _____ (T or F) All science subject matter should be taught through inquiry.

2. _____ (T or F) True inquiry occurs only when students generate and pursue their own questions.

3. _____ (T or F) Inquiry teaching occurs easily through use of hands-on or kit-based instructional materials.

4. _____ (T or F) Student engagement in hands-on activities guarantees that inquiry teaching and learning are occurring.

5. _____ (T or F) Inquiry can be taught without attention to subject matter.

Reference
SOME MYTHS ABOUT INQUIRY-BASED LEARNING AND TEACHING OF SCIENCE
(National Research Council, 2000, pp. 35-37)

Myth 1 – All science matter should be taught through inquiry.
The effective teaching of science requires a variety of approaches and strategies. “It is not possible in practice to teach all science subject matter through inquiry, nor is it desirable to do so. Teaching all of science using only one method would be ineffective, and it would probably become boring for students.” [p. 36]

Myth 2 – True inquiry occurs only when students generate and pursue their own questions.
“For students to develop the ability to ask questions, they must “practice” asking questions. But if the desired outcome is learning science subject matter, the source of the question is less important than the nature of the question itself. It is important to note, however, that in today’s science classrooms students rarely have opportunities to ask and pursue their own questions. Students will need some of these opportunities to develop advanced inquiry abilities and to understand how scientific knowledge is pursued.” [p. 36]

Myth 3 – Inquiry teaching occurs easily through use of hands-on or kit-based instructional materials.
“These materials can increase the probability that students’ thinking will be focused on the right things and learning will occur in the right sequence. However, the use of even the best materials does not guarantee that students are engaged in rich inquiry, nor that they are learning as intended. A skilled teacher remains the key to effective instruction. He or she must pay careful attention to whether and how the materials incorporate the five essentials of inquiry. Using these five features to review materials as well as to assess classroom practice should enhance the kinds and depth of learning.” [p. 36]

Myth 4 – Student engagement in hands-on activities guarantees that inquiry teaching and learning are occurring.
“Although participation by students in activities is desirable, it is not sufficient to guarantee their mental engagement in any of the five essential features of inquiry.” [p. 36]

Myth 5 – Inquiry can be taught without attention to subject matter.
“Some of the rhetoric of the 1960s was used to promote the idea that learning science processes should be the only meaningful outcome of science education. Today, there are educators who still maintain that if students learn the processes of science, they can learn any content they need by applying these processes. But as stated at the beginning of this chapter [ch. 2, pp. 13-37], student understanding of inquiry does not, and cannot, develop in isolation from science subject matter. Rather, students start from what they know and inquire into things they do not know. If, in some instances, a teacher’s desired primary outcome is that students learn to conduct an inquiry, science subject matter serves as a means to that end. Scientific knowledge remains important. The abilities and understandings outlines in the [NSES] Standards extend beyond the processes of science to engage students in a full complement of thinking and learning in science.” [pp. 36-37]
Reference
1. Learners are engaged by scientifically oriented questions.

2. Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions.

3. Learners formulate **explanations** from evidence to address scientifically oriented questions.

4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.

5. Learners communicate and justify their proposed explanations.

<table>
<thead>
<tr>
<th>ESSENTIAL FEATURE</th>
<th>VARIATIONS</th>
<th>----</th>
<th>----</th>
<th>----</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Learner engages in scientifically oriented questions</td>
<td>Learner poses a question</td>
<td>Learner selects among questions, poses new questions</td>
<td>Learner sharpens or clarifies a question provided by teacher, materials, or other source</td>
<td>Learner engages in question provided by teacher, materials, or other source</td>
</tr>
<tr>
<td>2. Learner gives priority to EVIDENCE in responding to questions</td>
<td>Learner determines what constitutes evidence and collects it</td>
<td>Learner directed to collect certain data</td>
<td>Learner given data and asked to analyze</td>
<td>Learner given data and told how to analyze</td>
</tr>
<tr>
<td>3. Learner formulates EXPLANATIONS from evidence</td>
<td>Learner formulates explanation after summarizing evidence</td>
<td>Learner guided in process of formulating explanations from evidence</td>
<td>Learner given possible easy to use evidence to formulate explanation</td>
<td>Learner provided with evidence</td>
</tr>
<tr>
<td>4. Learner connects explanations to scientific knowledge</td>
<td>Learner independently examines other resources and forms the links to explanations</td>
<td>Learner directed toward areas and sources of scientific knowledge</td>
<td>Learner given possible connections</td>
<td></td>
</tr>
<tr>
<td>5. Learner communicates and justifies explanations</td>
<td>Learner forms reasonable and logical argument to communicate explanations</td>
<td>Learner coached in development of communication</td>
<td>Learner provided broad guidelines to sharpen communication</td>
<td>Learner given steps and procedures for communication</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MORE</th>
<th>LESS</th>
<th>LESS</th>
<th>MORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>--- Amount of Learner self-direction</td>
<td>--- Amount of Directions from teacher</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reference
A. The following statements are about interweaving the nature of science (NOS) throughout our science teaching.
Instructions: a) Please indicate whether each of the following statements is True or False. b) For each item that you indicate as False, please write briefly your reason(s) for it being false.

1. _____ (T or F) Students should say they “prove” principles (like Charles’s law) in the science classroom, because this phrase is an extension of language they typically use outside the classroom.

2. _____ (T or F) Step-by-step science laboratory instructions help students understand that following investigative procedures carefully will result in certain knowledge.

3. _____ (T or F) Students should ask “What did the data tell us?”

4. _____ (T or F) Step-by-step science laboratory instructions help students understand that scientists are absolutely objective.

5. _____ (T or F) Most science textbooks portray the human influences in the history of science research accurately and in detail.

6. _____ (T or F) Assessment that emphasizes science vocabulary and the facts, concepts, and principles of science drives home the nature of science.

7. _____ (T or F) Students often learn accurate ideas about the nature of science simply by reading/watching historical and contemporary accounts of science in action.

8. _____ (T or F) It is quite difficult to use science assessment to further the students’ understanding of the nature of science.
NATURE OF SCIENCE

THE NATURE OF SCIENCE (NOS) SHOULD ALWAYS BE PART OF TEACHING SCIENCE
(Clough & Olsen, 2004, pp. 28-31)

“Accurately conveying the nature of science (NOS)—what science is and how it works—is common to most science education standards document (McComas & Olsen, 1998), including the National Science Education Standards (NRC, 1996) and Science for all Americans (AAAS, 1989). Understanding how science works is crucial to scientific literacy because bound up in content and public policy decisions involving science are issues regarding what science is, how knowledge in science comes to be accepted, and what science can and cannot do” (Clough & Olsen, 2004, p. 28).

UNINTENTIONALLY TEACHING MISTAKEN NOTIONS ABOUT NOS

“All science teachers and courses teach students about NOS whether or not they wish to. A few of the ways mistaken notions about NOS are conveyed to students include” (Clough & Olsen, p. 28):

Language – The language science teachers use when teaching science content;

Cookbook laboratories – The cookbook nature of many laboratory activities that convey mistaken notions about the processes of science.

Textbook – Textbooks that report the end products of science without addressing how the knowledge was developed.

Assessment – Common assessment strategies that emphasize vocabulary and the final conclusions of science.

SPECIFIC STRATEGIES FOR TEACHING NOS

Introducing NOS: Some examples

Puzzle-solving activities: Teachers have students solve brainteasers and then consider how solving such puzzles is like doing science (Clough, 1997).

“Black-box activity, and its common variations: Students explore a system, such as a sealed box containing common objects or a sealed tube with protruding ropes, and attempt to account for how it works, never being able to directly see its interior (see Lederman and Abd-El Khalick, 1998).

Pictorial gestalt switches: Examples like the old/young lady, rabbit/duck images, and M.C. Escher’s drawings help students understand that observations depend on prior observations and are not objective. “These can be used to illustrate how different interpretations can be constructed from the same data” (Clough & Olsen, 2004, p. 29).
Making inferences from limited data sets: Activities that require students to take a limited data set and make inferences are excellent ways to begin accurately portraying NOS” (Clough & Olsen, 2004, p. 29).

Importance of Language

“Words such as law, theory, prove, and true should be used carefully and students should be made aware of the importance of these words’ meanings. Statements such as ‘What did the data tell us?’ or ‘What did the data show?’ misportray NOS because data do not tell scientists what to think.

“When providing evidence for science ideas, NOS can seamlessly be incorporated by pointing out to students that the data are not telling the scientists what to think. Instead, scientists typically ask “What ideas can be developed to account for the data?” This shift in language creates opportunities to pose questions such as, “How does the need to make sense of data account for disagreement among scientists and the inventive character of science” (Clough & Olsen, 2004, p. 29).

Laboratory Activities

“Cookbook laboratory experiences imply that scientists are absolutely objective, that they follow prescribed steps in doing research, and that their conclusions follow obviously from the data collected. Typical laboratory instructions imply a step-by-step method for doing science and that doing science does not require creativity. Such experiences wrongly teach students that following procedures carefully will result in certain knowledge.

Instead, use well-designed inquiry laboratory activities and overtly draw students’ attention to important NOS issues as they analyze laboratory procedures, interpret data, create procedures, and raise questions to be investigated” (Clough & Olsen, 2004, p. 28).

Science Textbooks and NOS

“Science textbooks are notorious for downplaying human influences in research, sanitizing the processes that eventually result in knowledge, and portraying science as simply a lengthy list of conclusions. In the few instances when textbooks do mentions scientists, the process of science is sanitized through statements such as, “In 1953 Watson, Crick, and Wilkins discovered the structure of DNA and in 1962 were awarded the Nobel Prize.” Such phrases severely distort NOS by:

- neglecting the crucial role of Rosalind Franklin and others in the achievement.
- ignoring alternative ideas given considerable attention (triple helices and like-with-like nitrogen base pair bonding) but later abandoned.
- implying by the word discovered that the structure was found rather than created to account for data that were often very difficult to interpret.
“A valuable strategy to implement periodically throughout the school year is to have students critically analyze their textbook’s portrayal of NOS. Students can consider how written materials distort or ignore the:

- meaning of words such as law, hypothesis, theory, and prove.
- human side of science.
- assumptions underlying knowledge
- difficulties in research including making sense of data.
- Justification for conclusions.

(Clough & Olsen, 2004, p. 28).

Assessment

“Teachers should ensure that formal tests, laboratory write-ups, and other assignments emphasize NOS. For example, on a chemistry examination, students can be referred back to a laboratory activity regarding the kind of substances or products form when NaHCO$_3$(aq) and CaCl$_2$(aq) react (Clough & Clark, 1994) and ask how the activity accurately and inaccurately portrays NOS. On a biology exam students might address experimental work done in the mid-twentieth century regarding the identification of DNA as the genetic material, the resistance of some scientists to accept that interpretation, and what that episode illustrates about NOS” (Clough & Olsen, 2004, p. 28).

Process of Science

Despite the strategies mentioned above for teaching NOS, students can still cling to their misconceptions by discrediting these attempts and claiming that what has been occurring in class (e.g., black box activities) is not what real scientists do.

“Just as science teachers often use hands-on activities as evidence to convince students of science concepts, historical and contemporary episodes of science in action can serve as evidence to convince students of more accurate NOS ideas. Many readings exist that directly target accurate portrayals of NOS. For example, at an appropriate time in the course, students can read portions of Peter Medawar’s (1963) ‘Is the scientific paper a fraud?’ Medawar illustrates how the systematic way investigations are conveyed in journals distorts how science research actually occurs” (Clough & Olsen, 2004, p. 28).

“Evidence for how science works is readily available in historical and contemporary examples tied to fundamental science ideas taught in particular subjects.” Portions of the following works may be used to enhance students’ understanding of science content and how science works: A Revolution in Earth Sciences (Hallam, 1973), The Big Splash (Frank, 1990) when studying the origin of Earth’s water, and Nailing Down Gravity (Folger, 2003).

“Teachers must play an active role in posting questions as strategic points to explicitly draw students’ attention to NOS ideas. Just as students rarely develop accurate science ideas from activities alone, accurate NOS ideas will not be learned simply by doing activities or reading/watching historical and contemporary accounts of science in action” (Clough & Olsen, 2004, p. 28).
References


NATURE OF SCIENCE

TEACHING AND THE NATURE OF SCIENCE (NOS)
(McComas, 2004, pp. 24-27)

“NOS is the sum total of the “rules of the game” leading to knowledge production and evaluation of truth claims in the life sciences” (McComas, 2004, p. 25)

“The National Science Education Standards specifically includes standards focusing on science as a human endeavor and the nature of science across all grade levels (McComas, 2004, p. 24; NRC, 1996, pp. 141, 170-171, 200-201).”

CORE NOS IDEAS

1. Science demands and relies on empirical evidence

   Not all evidence is gained through experimental means, although that is frequently called the ‘gold standard’ of science. “In addition to experiments with their rigorous tests and controls, science also relies on basic observations (consider the work of Fossey, Goodall, and Galdikas as they studied the great apes) and the historical explorations that have added so much to our understanding of the fossil record and geology generally” (McComas, p. 25).

2. Knowledge production in science includes many common features and habits of mind. However, in spite of such commonalities, there is no single step-by-step scientific method by which all science is done.

   “Although common features in the practice of science, like logical reasoning and careful data collection are part of all good science, there is no universal set of steps that begin with “defining the problem,” extend to “forming a hypothesis,” “testing a hypothesis,” and finish with “making conclusions” and “reporting results” (McComas, p.25).

   Such a stepwise method commonly provided in science textbooks may be effective as a research tool, but there should be no implications in classroom discussions that all scientists use any single method routinely. In fact, studies of scientists at work reveal many idiosyncratic ways of approaching research and even of coming up with research problems in the first place” (McComas, p. 25).

3. Scientific knowledge is tentative but durable. This means that science cannot prove anything because the problem of induction makes “proof” impossible, but scientific conclusions are still valuable and long lasting because of the way that knowledge eventually comes to be accepted in science.

   “Induction is the knowledge generation process by which individual data points related to the problem or phenomenon are gathered until a general trend, principle, or law emerges from this mass of data. Prediction and deduction are used to evaluate the validity of the initial conclusion.
“The cycle of induction and deduction, a hallmark of logic, is far from perfect. There is simply no way to know that one has amassed all of the relevant data nor is there any way to be sure that the generalization suggested will hold true for all space and time.

However, the logical knowledge generation process described briefly here is the best we have yet developed to provide ideas that are both useful and valid despite an inability to offer absolute proof. We can have confidence that scientific conclusions formed in this fashion will be long lasting or durable because of the rigorous, self-correcting nature of the scientific process and the requirement that conclusions are agreed to by consensus of the scientific community” (McComas, 2004, pp. 25-26).

WHAT IS NOS?

4. Laws and theories are related but distinct kinds of scientific knowledge

“Laws are generalizations or patterns in nature (such as Charles’s law), while theories are explanations for why such laws hold (such as the kinetic molecular theory of matter, which suggests that tiny particles behaving like billiard balls become more active as temperature rises)” (McComas, p. 26).

5. Science is a highly creative endeavor.

“Scientists, through their selection of problems and methods for investigation, would certainly agree that their work is creative. …The knowledge generation process in science is as creative as anything in the arts, a point that would be made clearer to students who examine process as well as content.

“Unfortunately, the average student is more likely to describe science as a dry set of facts and conclusions rather than a dynamic and exciting process that leads to new knowledge. In our quest to teach students what has already been discovered, we typically fail to provide sufficient insights into the true and creative NOS exploration” (McComas, p. 26).

6. Science has a subjective element.

Because of its status as a human activity, science has a subjective component. “Two scientists looking at the same data may ‘see’ and respond to different things because of their prior experiences and expectations. This does not make science less rigorous or useful since ultimately the results will have to be discussed and defended before the larger scientific community. However, the initial discovery and analysis are ultimately personal and uniquely subjective events” (McComas, p. 26).

7. There are historical, cultural, and social influences in science.

“Science is a large and powerful enterprise that lies within the greater human social system. What research is performed and what research is discouraged or even prohibited is best understood by considering human forces such as history, religion, culture, and social priorities.
The debate regarding stem cell research and therapeutic human cloning is a current example of the interplay of science and cultural forces” (McComas, p. 26).

8. Science and technology impact each other, but they are not the same.

“Roughly speaking there are two kinds of problems investigated by modern science. Some problems relate to a particular need such as how to produce a more effective or less expensive music storage device, how to increase the agricultural yield of a plot of land, or how to vanquish a particular disease—all worthy endeavors. These challenges are technological in nature and represent what is frequently called ‘applied’ science. On the other hand, ‘pure’ science aims at knowledge sake (McComas, p. 26).


“One of the most important elements of NOS is for students to understand that limits exist to science and to appreciate that some questions simply cannot be investigated using scientific means. For instance, it may be possible to determine what percentage of the population likes a particular work of art, but it would be unreasonable to expect that science could fully explain why such an opinion exists. Such is often the case with questions of morality, ethics, and faith—for many the domain of religion.”

“Knowing that science cannot and should not address all questions is vital if we are to avoid the common but false premise that science and religion are at war” (McComas, p. 27).

References


Nature of Science
HOW DO SCIENTISTS THINK SCEPTICALLY?
[BASED ON: THE “BALONEY DETECTION KIT” IN SAGAN, 1996, PP. 210-213.]

IN SCIENCE:

1. _____ (T or F) We trust persons who are known authorities in an area to tell us whether we are correct. [Arguments from Authority]

2. _____ (T or F) When, faced with two hypotheses that explain the same data equally well, we tend to choose the more complex hypothesis. [Occam’s Razor]

3. _____ (T or F) Whatever has not been proved false must be true. Example: “There is no compelling evidence that UFOs are not visiting the earth; therefore UFOs must exist.” [Appeal to Ignorance]

4. _____ (T or F) We only need one good hypothesis, instead of several competing hypotheses. [Multiple Working Hypotheses]

5. _____ (T or F) If almost all of the links in our chain of reasoning are logical, we know we are probably correct. [Logical Chain of Reasoning]

6. _____ (T or F) We consider only the evidence that supports our hypothesis. Example: A state boasts of the presidents it has produced, but is silent on its serial killer. [Observational Selection]

7. _____ (T or F) We don’t really worry whether our hypothesis is in a form that would allow others to test it, if we know it’s a good hypothesis. [Falsifiable Hypothesis]

8. _____ (T or F) It is allowed to attack the person who disagrees with our hypothesis, rather than attack his or her hypothesis and information. [ad hominem argument]

9. _____ (T or F) The persons with hopes for a certain research finding should always be the ones evaluating the experimental results. [Double-Blind Experiments]

10. _____ (T or F) We claim that a person who disagrees with us just doesn’t understand the theory involved. Example: “You don’t understand the doctrine of…” [Special Pleading]

11. _____ (T or F) We caricature a position we disagree with, to make it easier to attack. Example: “Scientists suppose that living things simply fell together by chance.” [Straw Man]

12. _____ (T or F) We consider only two extremes in a continuum of immediate possibilities. Example: “If you’re not part of the solution, you’re part of the problem.” [Excluded Middle or False Dichotomy]

13. _____ (T or F) We concentrate on only short-term solutions or long-term solutions, not both. Example: “We can’t afford to feed malnourished children and educate pre-school kids. We need
urgently to deal with crime on the streets.” [Short-term vs. Long-Term, a subset of Excluded Middle]

14. _____ (T or F) We take correlation to mean causation without considering similar situations. Example: “Andean earthquakes are correlated with the closest approaches of the planet Uranus; therefore the latter causes the former.” (This despite the absence of any such correlation for the nearer, more massive planet Jupiter.) [Slippery Slope related to Excluded Middle]

15. _____ (T or F) We need not to look for other confirming evidence of the action of the causes we cite for the case we are considering. Example: “The stock market fell yesterday because of a technical adjustment and profit-taking by investors.” [Begging the Question or Assuming the Answer]

16. _____ (T or F) We know that if something happens right after another thing, the first causes the second. Example: “Before women got the vote, there were no nuclear weapons.” [post hoc, ergo propter hoc]
HOW DO SCIENTISTS THINK SKEPTICALLY?
SOME HELPFUL TOOLS
(SAGAN, 1996, pp. 210-213)

“In science we may start with experimental results, data, observations, measurements, ‘facts.’” We invent, if we can, a rich array of possible explanations and systematically confront each explanation with the facts.

”BALONEY DETECTION KIT”
“In the course of their training, scientists are equipped with a baloney detection kit. The kit is brought out as a matter of course whenever new ideas are offered for consideration. If the new idea survives examination by the tools in our kit, we grant it warm, although tentative, acceptance” (pp. 209-210).

SKEPTICAL THINKING
“Skeptical thinking is “the means to construct and to understand, a reasoned argument and--especially important--to recognize a fallacious or fraudulent argument” (p. 210).

Independent confirmation: whenever possible.

Substantive debate: on the evidence by knowledgeable proponents of all points of view.

Arguments from authority: carry little weight. “Authorities have made mistakes in the past. In science there are no authorities; at most there are experts.

Multiple working hypotheses: Spin more than one hypothesis. ... Then think of tests by which you might systematically disprove each of the alternatives.

Over-attachment to a hypothesis: Try not to get overly attached to a hypothesis just because it’s yours. The hypothesis is only a way station in the pursuit of knowledge.

Quantify: If whatever it is you’re explaining has some measure, some numerical quantity attached to it, you’ll be much better able to discriminate among competing hypotheses.

Logical chain of reasoning: If there’s a chain of argument, every link in the chain must work (including the premise)--not just most of them.

Occam’s Razor: This convenient rule of thumb urges us, when faced with two hypotheses that explain the data equally well, to choose the simpler hypothesis.

Falsifiable hypotheses: Always ask whether the hypothesis can be, at least in principle, falsified. Propositions that are untestable, unfalsifiable are not worth much.
EXPERIMENTAL DESIGN
“The reliance on carefully designed and controlled experiments is key ...” (p. 211).

Control experiments: are essential.

Variables: must be separated.

Double-blind experiments: Often the experiment must be done “double-blind,” so that those hoping for a certain finding are not in the potentially compromising position of evaluating the results.

WHAT NOT TO DO
“... any good baloney detection kit must also teach us what not to do. It helps us recognize the most common and perilous fallacies of logic and rhetoric” (p. 212).

ad hominem argument: Latin for “to the man,” this means attacking the arguer and not the argument.

Argument from authority: For example, the president should be reelected because he has a secret plan to end the war. But, of course, the electorate cannot evaluate the plan because it is secret.

Argument from adverse consequences: For example, a certain thing must be true; otherwise much worse things would be happening.

Appeal to ignorance: The claim that whatever has not been proved false must be true, and vice versa. For example, “there is no compelling evidence that UFOs are not visiting the Earth; therefore UFOs must exist ...” (Sagan, 1996, p. 213).

Special pleading: Often used to rescue a proposition in deep theoretical trouble. For example, “You don’t understand the doctrine of ...”

Begging the question: Also called “assuming the answer.” For example, “the stock market fell yesterday because of a technical adjustment and profit-taking by investors.” But is there any independent evidence for the causal role of “adjustment” and “profit-taking” (Sagan, 1996, p. 214).

Observational selection: Also called the “enumeration of favorable circumstances.” Francis Bacon called this “courting the hits and forgetting the misses” (Sagan, 1996, p. 214). For example, a state boasts of the presidents it has produced, but is silent on its serial killers.

Statistics of small numbers: A close relative of “observational selection.” For example, “They say 1 out of every 5 people is Chinese. I know hundreds of people, and none of them is Chinese” (Sagan, 1996, p. 214).
Misunderstanding of the nature of statistics: For example, a person’s surprise that fully half of all Americans have below average intelligence.

Inconsistency: For example, prudently plan for the worst of which a military is capable, but thriftily ignore scientific projections on environmental dangers because they’re not “proved” (Sagan, 1996, p. 214).

non sequitur: Latin for “It doesn’t follow.”

post hoc, ergo propter hoc: Latin for “It happened after, so it was caused by.” For example, “Before women got the vote there were no nuclear weapons” (Sagan, 1996, p. 214).

Meaningless question: For example, “What happens when an irresistible force meets an immovable object?” But if there is such a thing as an “irresistible force,” there can be no immovable objects, and vice versa (Sagan, 1996, p. 215).

Excluded middle, or “false dichotomy”: “Considering only the two extremes in a continuum of intermediate possibilities.” For example, “If you’re not part of the solution, you’re part of the problem” (Sagan, 1996, p. 215).

Short-term vs, long-term: A subset of the “excluded middle.” For example, “We can’t afford to feed malnourished children and educate pre-school kids. We need urgently to deal with crime on the streets (Sagan, 1996, p. 215).

Slippery slope: Related to “excluded middle.” For example, “Andean earthquakes are correlated with the closest approaches of the planet Uranus; therefore the latter causes the former.” This, despite the absence of any such correlation for the nearer, more massive planet Jupiter (Sagan, 1996, p. 215).

Straw man: Caricaturing a position to make it easier to attack. For example, “Scientists suppose that living things simply fell together by chance.”

Suppressed evidence, or “half-truths”: For example, “These government abuses demand revolution, even if you can’t make an omelette without breaking some eggs.” But does the experience of other revolutions suggest that all revolutions against oppressive regimes are desirable and in the interests of the people? (Sagan, 1996, p. 216).

Weasel words: For example, politicians who create euphemisms for odious institutions.

REFERENCE
CLASSROOM ASSESSMENT PRETEST


The following statements are about assessing classroom learning.
Instructions: a) Please indicate whether each of the following statements about assessing classroom learning is True or False. b) For each item that you indicate as false, please write briefly your reason(s) for it being false.

1. _____ (T or F) **Purposes of formative assessment are grading, placement, promotion, and accountability.**

2. _____ (T or F) **Purposes of summative assessment are to improve learning and to inform instruction.**

3. _____ (T or F) **The teacher and the student(s) are responsible for summative assessment.**

4. _____ (T or F) **Teachers and external tests are responsible for formative assessment.**

5. _____ (T or F) **Today the emphasis of formative assessment is on assessing what is easily measured.**

6. _____ (T or F) **Today the emphasis of formative assessment is on assessing discrete knowledge.**

7. _____ (T or F) **Today the emphasis of formative assessment is on assessing scientific knowledge.**

8. _____ (T or F) **Today the emphasis of formative assessment is on learning what students do not know.**

9. _____ (T or F) **Today the emphasis of formative assessment is on end-of-term assessment by teachers.**

10. _____ (T or F) **Today the emphasis of formative assessment is on development of external assessments by experts alone.**
CLASSROOM ASSESSMENT
(NRC, 2001)

“Assessment is a ubiquitous part of classroom life. Most exchanges between teacher and students are on occasion for considering the quality of student work. Often informal, assessment is a natural feature of teaching and learning whether or not it is so identified by teachers or students” (NRC, 2001, p. 1).

CHANGING EMPHASES OF FORMATIVE ASSESSMENT

“A major impetus behind the standards movement is the expectation that all students are to achieve the high standards. To reach that goal, greater attention to classroom assessment that supports learning becomes particularly compelling, and teachers and researchers need to focus attention on how classroom assessment can be used as a means to this end. Assessment tools that calculate solely how well student achievement measures up to the standards, however reliable, will not suffice.”

“Assessment must also serve as a vehicle for improving the quality of learning for every student. There is a clear and indivisible connection among assessment, curriculum, and teaching” (NRC, 2001, p. 19).

TABLE. Changing Emphases of Formative Assessment
(NRC, 2001, Table 2-1, p. 19)

<table>
<thead>
<tr>
<th>Less Emphasis On</th>
<th>More Emphasis On</th>
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</thead>
<tbody>
<tr>
<td>Assessing what is easily measured</td>
<td>Assessing what is most highly valued</td>
</tr>
<tr>
<td>Assessing discrete knowledge</td>
<td>Assessing rich, well-structured knowledge</td>
</tr>
<tr>
<td>Assessing scientific knowledge</td>
<td>Assessing scientific understanding and reasoning</td>
</tr>
<tr>
<td>Assessing to learn what students do not know</td>
<td>Assessing to learn what students understand</td>
</tr>
<tr>
<td>End-of-term assessment by teachers</td>
<td>Students engaged in ongoing assessment of their work and that of others</td>
</tr>
<tr>
<td>Development of external assessments by measurement experts alone</td>
<td>Teachers involved in the development of external assessments</td>
</tr>
</tbody>
</table>

TYPES, PURPOSES, AND ROLES & RESPONSIBILITIES FOR ASSESSMENT

“Black (1997) categorizes the purposes of assessment into those concerned with a) support of learning; b) certification, which includes reporting individual achievement, or grading, placement, and promotion; and c) accountability.” (NRC, 2001, pp. 19-20)

TABLE. Types, Purposes, and Roles and Responsibilities for Assessment
(NRC, 2001, Table 2-2, p. 20)

<table>
<thead>
<tr>
<th>Type</th>
<th>Purpose</th>
<th>Roles and Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formative</td>
<td>Improve learning.</td>
<td>Student and teacher</td>
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<tr>
<td></td>
<td>Inform instruction.</td>
<td></td>
</tr>
<tr>
<td>Summative</td>
<td>Grading</td>
<td>Teachers and external tests</td>
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<tr>
<td></td>
<td>Placement</td>
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<td></td>
<td>Promotion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accountability</td>
<td>External tests (and teacher)</td>
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</tbody>
</table>

FRAMEWORK OF ASSESSMENT APPROACHES AND METHODS

“The form that the assessment takes should coincide with careful consideration of the intended purpose.” “The use of the data generated by and through the assessment is important so that it feeds back into the teaching and learning” (NRC, 2001, p. 63). As shown in the table below, “McTighe and Ferrara (1988) provide a useful framework for selecting assessment approaches and methods. The table accents the range of common assessment available to teachers. Although their framework serves all subject-matter areas, the wide variety of assessments and assessment-rich activities could be applicable for assessments in a science classroom” (NRC, 2001, pp. 63-64.)
Framework of Assessment Approaches and Methods
(NRC, 2001, Table 4-1, p. 63)

<table>
<thead>
<tr>
<th>HOW MIGHT WE ASSESS STUDENT LEARNING IN THE CLASSROOM?</th>
</tr>
</thead>
<tbody>
<tr>
<td>SELECTED-RESPONSE FORMAT</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>• Multiple-choice</td>
</tr>
<tr>
<td>• True-false</td>
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<tr>
<td>• Matching</td>
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<tr>
<td>• Enhanced multiple choice</td>
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<tr>
<td>Brief Constructed Response</td>
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<tr>
<td>• Fill in the blank</td>
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<tr>
<td>• Word(s)</td>
</tr>
<tr>
<td>• Phrase(s)</td>
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<tr>
<td>• Short answer</td>
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<tr>
<td>• Sentence(s)</td>
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<tr>
<td>• Paragraphs</td>
</tr>
<tr>
<td>• Label a diagram</td>
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<tr>
<td>• “Show your work”</td>
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<tr>
<td>• Visual representation</td>
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<tr>
<td>• Essay</td>
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References

