What the Bleep Do We Know?

A Discussion on the Nature of Science

$$\frac{XXIII}{VII} = II$$

I SEE

I WONDER

I TRY

I SEE BETTER

I WONDER MORE

I TRY MORE

I SEE MORE

I UNDERSTAND

ETC.

~Philip Roskos
Lakeland Community College
Mentor, OH

Presenters:

Jamie Benigna
The Roeper School
jamie.benigna@roeper.org

Pat Vance
Education Consultant
pat@vance.com

Session Outline:

I. The Puzzle
   a. Roman Numerals
   b. What do you see?

II. The Nature of Science – Core Ideas

III. The Scientific Method
   a. "Why THE Scientific Method?"
   b. Diagramming methods

IV. The Importance of Language – What Not to Say and Why

V. History shapes Chemistry
   a. Timeline of Atomic Theory
   b. Current political influences and the funding game

VI. Inquiry – doing science
   a. Making inquiry manageable
   b. Inquiry happens outside of the lab
   c. Chemistry Inquiry (www.chemistryinquiry.com)
   d. Discrepant Events

VII. Assessment
   a. Questioning styles
   b. Making higher-order assessment manageable
   c. Informal and open-ended assessments
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VIII. References, Glossary, and Relevant Quotes

IX. Wrap-up and Questions

THE NATURE OF SCIENCE: CORE IDEAS

William McComas, in an article in the November, 2004, *Science Teacher*, states that a consensus of key Nature of Science ideas appropriate for inclusion in the K-12 science curriculum has begun to emerge. This is a summary of those key ideas.

1. Science demands and relies on empirical evidence.

Data, open to review by others, must be provided to justify all final conclusions. Many ideas may begin as exploratory notions, but before they are accepted, evidence must be gathered and presented. While the "gold standard" of science is evidence gathered through experimental means, science also relies on basic observations and historical explorations. Faith alone in the correctness of one's views plays no final role in science.

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

The stepwise method commonly provided in textbooks may be effective as a research tool, but there should be no implication in classroom discussions that all scientists use any single method routinely.

3. Scientific knowledge is tentative but durable. 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.

There is 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. The scientific process is rigorous and self-correcting and requires that conclusions are agreed to by the consensus of the scientific community.

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

One of the most resilient misconceptions about science is that laws are mature theories and, as such, are more believable or valuable than are theories. Laws are generalizations or patterns in nature, while theories are explanations for why such laws hold.

5. Science is a highly creative endeavor.

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. Some studies have shown that otherwise bright students reject science as a career choice simply because they have had no opportunity to see the creativity involved.

6. Science has a subjective element.

Initial discovery and analysis are ultimately personal and involve the scientist's prior experiences and expectations. This does not make science less rigorous and useful since ultimately the results will have to be discussed and defended before the larger scientific community. The prior insights that some scientists bring to the process of investigation explain why some individuals make monumental breakthroughs and others do not.

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

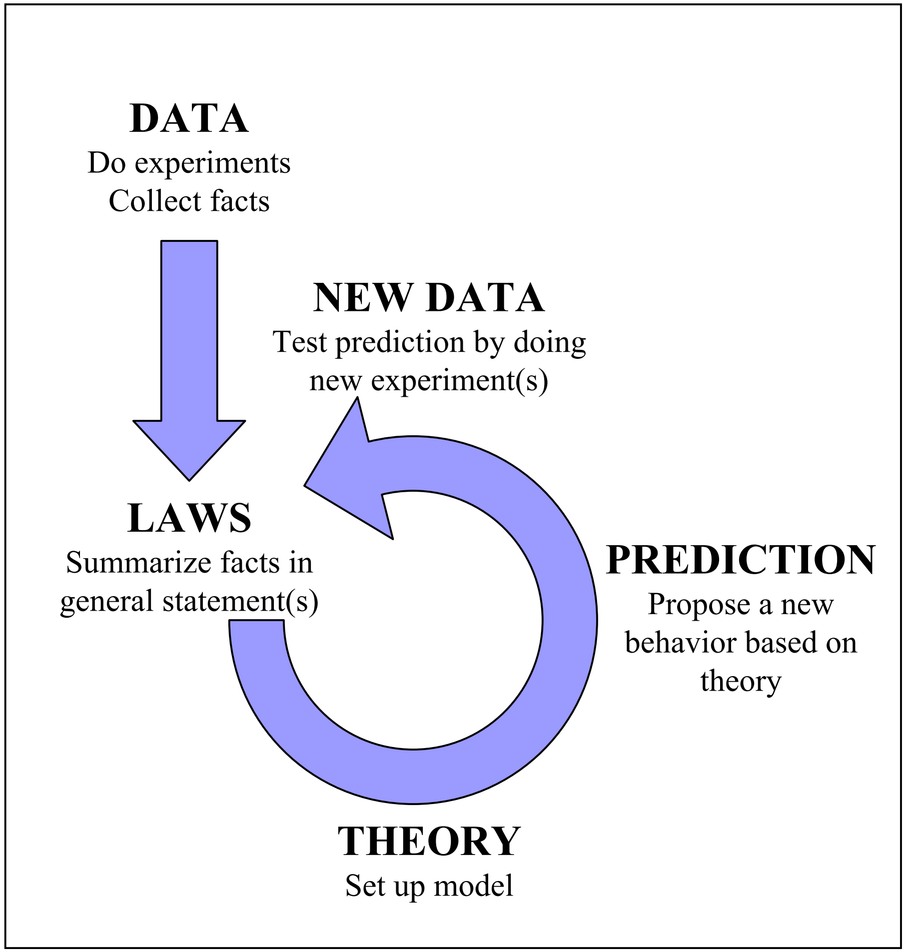
Some kinds of research are favored and some are discarded because of these influences.

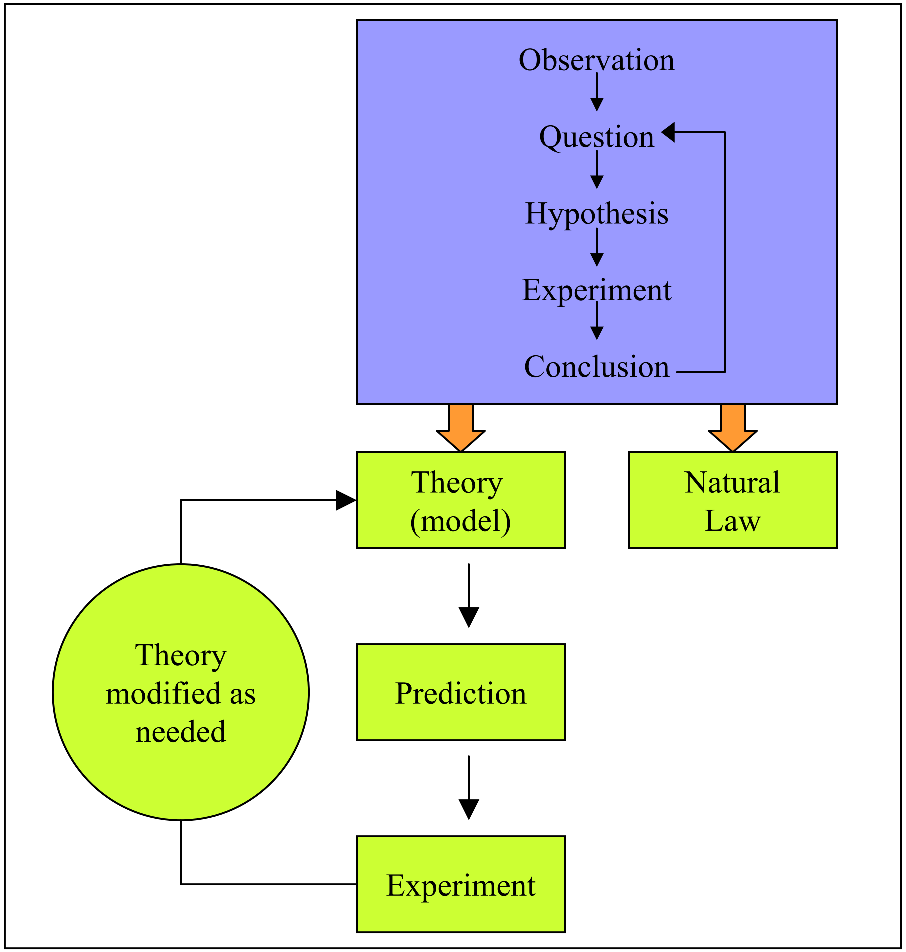
8. Science and technology impact each other, but they are not the same.

There are two kinds of problems investigated by modern science. Some relate to a particular need and are technological in nature, sometimes called "applied science." Others, however, involve "pure" science, which aims at basic understanding of the fundamental nature of reality. This sometimes leads to technological applications, but that is not its goal.

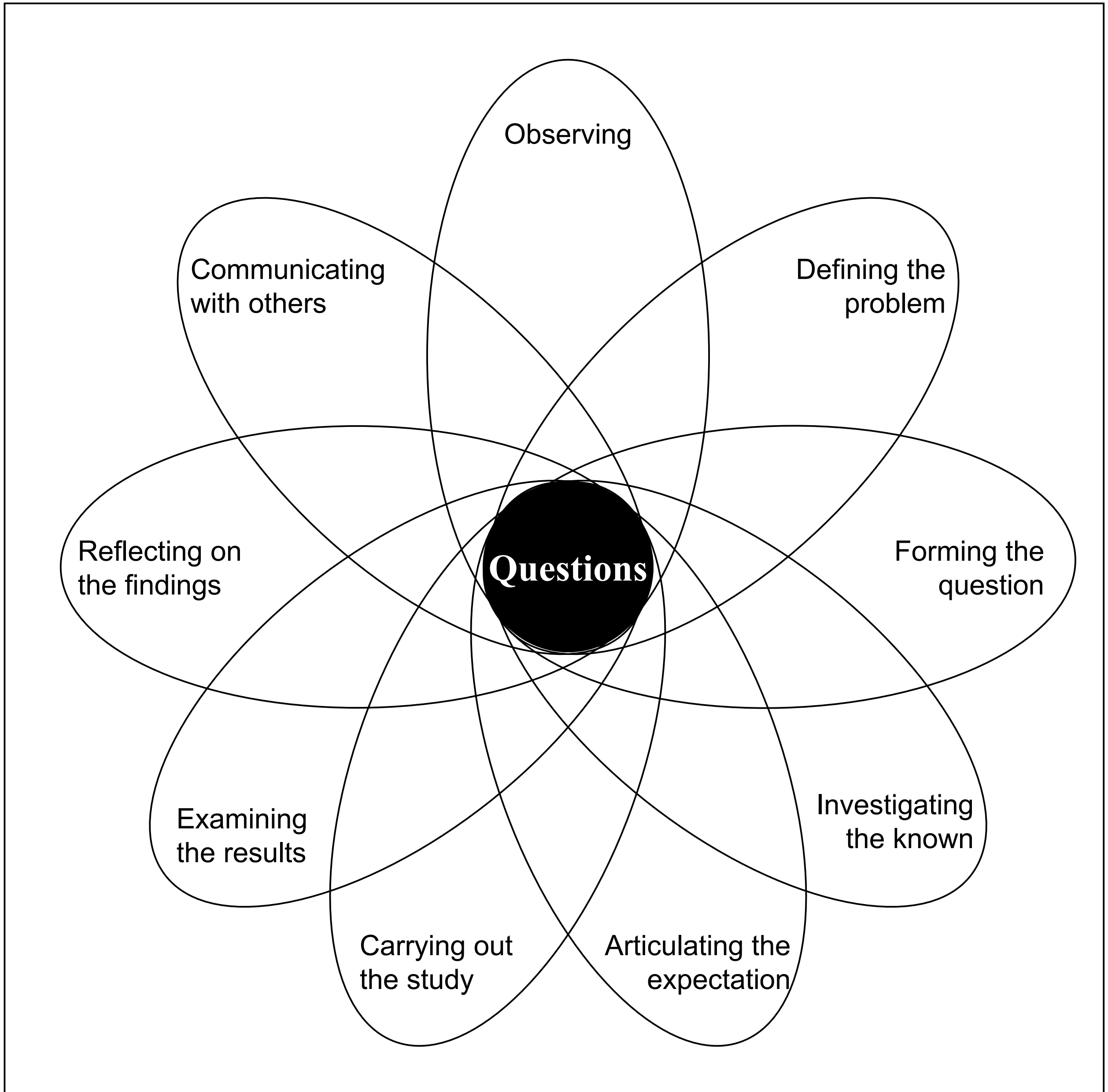
9. Science and its methods cannot answer all questions.

Limits exist to science and some questions simply cannot be investigated using scientific means. Questions of morality, ethics and faith are often the domain of philosophy and religion. Understanding 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.





Excerpted from various textbooks. See References page.



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HAVING LANGUAGE REFLECT THE TRUE NATURE OF SCIENCE

WHAT NOT TO SAY:	**WHY NOT:**
• "Prove"	Science doesn't prove anything.
• "What did the data tell us?" • "What do the data show?"	Data do not tell scientists what to think.

INSTEAD SAY:
"What ideas can be developed to account for the data?"

THIS COULD GIVE RISE TO THE OPORTUNITY TO POSE FRUITFUL QUESTIONS SUCH AS:

- "How does the need to make sense of the data account for disagreements among scientists and for the inventive character of science?"
- "Is having a solution with recognized problems better than no solution?"
- "Is valid scientific knowledge determined by majority rule?"
- "Are there unspoken rules that should govern proposed solutions to a problem?"
- "If there is disagreement among scientists as to the solution or interpretation of data, what would appear in textbooks?"

IN AN INQUIRY-FOCUSED, INVESTIGATIVE-ORIENTED, STANDARDS-BASED PROGRAM. . .

What Are Students Doing?	What Are Teachers Doing?
• Exploring • Investigating • Discussing • Writing • Analyzing • Representing • Organizing • Modeling • Visualizing • Constructing • Developing • Conjecturing • Validating • Convincing • Predicting • Explaining • Extending • Generalizing • Interpreting • Reflecting • Applying • Evaluating	• Creating a Learning Environment • Challenging • Facilitating • Nurturing • Reflecting • Guiding • Listening • Questioning • Clarifying • Discussing • Re-Directing • Extending • Evaluating

Inquiry is central to learning.

<u>When engaging in inquiry</u>, students

. describe objects and events,

. ask questions,

. construct explanations,

. test those explanations against current knowledge,

. communicate their own ideas to others,

. identify their assumptions,

. use critical and logical thinking,

. consider alternative explanations.

<u>In this way,</u> students actively develop their understanding by combining knowledge with reasoning and thinking skills.

Adapted from the National Science Education Standards, 1996, p. 3

A Timeline of Atomic Structure

with annotations of important technological developments

Technology	Year	Atomic Structure
	~400 B.C.	Democritus philosophizes that matter is made up of atoms, small indestructible spheres
	~400 B.C.	Aristotle proposes all matter is simply different forms of the same substance. Earth can be formed from water (dissolved minerals that wash off the mountains), water can turn to air (evaporation), and air can turn to water (rain).
portable clock	1500	
pencil	1565	
thermometer	1592	
telescope	1609	
	1620	Francis Bacon, in his *Novum Organum*, broke with Aristotle's metaphysical notions of elements. He also described heat as the motion of particles from which matter is composed.
multiplcation sign (x)	1631	
vacuum pump	1654	
	1666	Boyle writes about small, solid, physically indivisible particles that are the building blocks of nature in *The Origins of Forms and Qualities*.
artificial water filtration	1676	Boyle describes fire as small particles in rapid motion, which acccounted for heat. He sealed various metals in glass flasks and heated them strongly to convert them to their calces (oxides). Lavoisier later confirmed Boyle's experiments.
	1680	In the *Sceptical Chymist*, Boyle proposes the idea of compounding particles to make new substances.
	1679-1690	Becher proposes the phlogiston theory to explain the increase in mass when objects are burned.
steam engine	1712	
	1717	Newton's *Opticks* discusses corpuscles (particles) as a means to explain the transparency and opacity of various materials. He concluded that matter must consist mainly of empty space, and he estimated the size of the particles to be so small that all of the particles in the universe would have the volume of a nut if they were brought together. In other publications, Newton also explained solids and liquids as existing due to attractive forces between the particles.
steel production	1742	
eyeglasses	1758	
fire extinguisher	1762	
	1774	Lavoisier conducts his 12-day experiment of heating mercury in air in a sealed vessel. He found that 5/6 of the volume of the air had been consumed and that the mass of the reddish powder and the mercury had increased by the same amount.
flush toilet	1778	

Technology	Year	Atomic Structure
hot air balloon	1782	Lavoisier's experimental evidence leads him to reject the phlogiston theory.
steamboat	1786	
	1792	Lavoisier's views on oxygen and burning are ratified by the greater scientific community.
ball bearings	1794	Lavoisier's head drops into the basket of the guillotine in Paris.
smallpox vaccine	1796	
storage battery	1800	
	1808	Dalton publishes *A New System of Chemical Philosophy*, in which he details the law of constant composition. He predicted the law of multiple proportions from his theory and established it experimentally.
	1808	Gay-Lussac establishes that two volumes of gases combine in simple proportions.
	1811	Avogadro proposes his hypothesis that the volume of a gas is directly related to the number of particles contained.
locomotive	1814	
stethoscope	1816	
dental fillings	1819	
matches	1830	
telegraph	1837	
dynamite	1864	
bicycle	1867	
	1870	J.J. Thompson works in the Cavendish Lab at Cambridge, stabilizing cathode ray tubes (CRT) with electric and magnetic fields
DC electric motor	1873	
telephone	1876	
internal combustion engine	1877	
light bulb	1879	
electric fan	1882	
gas engine automobile	1885	
AC electric motor	1888	
flashlight	1891	
zipper	1891	
viruses discovered	1892	
moving pictures	1895	Roentgen accidentally discovers X-rays by glancing at a fluorescent screen on the bench next to his CRT experiment.
	1896	Becquerel leaves a block of uranium salt on photographic film in a cabinet for 2 days due to lack of a sunny day. His original experiment was trying to develop phosphorescent materials by irradiating them with sunlight. Both the irradiated rock and shaded rock produced an outline on the film. Becquerel handed his work over to the Curies.
	1897	J.J. Thompson's CRT experiments lead him to conclude that atoms must contain a negatively charged particle, which he called the "electron."
	1898	Boltzmann publishes his Kinetic Theory of Gases
paper clip	1900	
air conditioning	1902	
airplane	1903	

Technology	Year	Atomic Structure
	1905	Einstein publishes three papers in Annalan der Physik: special relativity, interaction of light with electrons, and an explanation of Brownian Motion as a function of statistical mechanics resulting from the collisions with other atoms.
	1906	Boltzmann, ill, depressed, and facing increasing opposition to his kinetic theory, commits suicide; he was completely unaware of Einstein's paper which irrefutably supported his kinetic theory of atoms.
	1907	Thompson and Goldstein describe the proton.
	1908	Rutherford is awarded the Nobel Prize in Chemistry. He often mocked this event since he was a physicist, and he considered Chemistry to be an inferior science.
	1909	Working under Ernest Rutherford, Hans Geiger and Ernest Marsden conduct the gold foil experiment, where alpha particles are deflected back toward the particle source.
	1911	Rutherford proposes a new model of the atom with a dense, positively-charged nucleus.
	1913	Thompson reasons that if electrons are coming from the atoms that the atoms must now be charged particles. He tunes his CRT experiments to investigate ions, observing that Neon gas gives 3 ions, all +1 charge, with 3 different masses.
	1913	Attempting to explain why a negatively-charged electron would not crash into the positively charged nucleus, Bohr proposes a "solar-system" model to the atom
stainless steel	1913	Bohr uses his solar system model to fully explain the emission spectrum of hydrogen.
	1914	World War I - Bohr, Rutherford, and Thompson are too old to serve in the military and carry on the research and scientific journals. Research is halted in Germany, France, and England. Denmark, in particular Copenhagen, becomes a center of chemical research.
AM radio	1915	
	1916	
	1917	
domestic refrigerator	1918	
	1919	Rutherford announces the first artificial transmutation of an element
hydraulic car brakes	1921	
aerosol can	1926	
artificial rubber	1926	
penicillin	1928	
vitamin C	1928	
blood bank	1931	
nylon	1932	Chadwick demonstrates the existence of the neutron.
ballpoint pen	1938	
fluorescent lights	1938	
television	1939	

DOING INQUIRY: IN THE LAB AND CLASSROOM

Teachers' complaints about doing inquiry labs include such things as

1) They take up too much time.
2) The students are totally confused and frustrated.
3) They take a lot of teacher preparation time.

Here are some tips for managing inquiry labs:

A) Make sure you increase student responsibility and independence gradually. Start out small, with manageable steps. Never give kids more than you are sure they can handle. In this manner, their confidence increases until they are handling the entire process themselves.

B) To cut teacher prep and checking time, put students in groups of 3 or 4; require only one lab report per group; limit choices of questions to be investigated.

C) Have each group turn in their proposed procedure ahead of the time they will be doing the lab. Then use baskets, shoeboxes, pneumatic troughs, etc to hold everything they will need for their lab. Code these to match a code you put on their procedure paper. Write any safety precautions on their paper as well.

D) Make a specific grading rubric to spell out what you want included in the group lab report. Especially early in the year, when the process of doing inquiry is the main goal of the lab activity, reward at least 80% of the grade for simply going through the process and having all parts of the lab report in place. Success brings confidence!

In the classroom, inquiry takes place through student analysis of discrepant events, through discussion of demonstrations, through open-ended questioning and through written materials designed to promote interpretation and higher-level thinking.

ASSESSMENT THAT PROMOTES NOS UNDERSTANDING

1. **All written assessments should include all three levels of questions:**
   a) input – "Name the parts…" "Give three examples of …"
   b) processing – "How does a solution differ from a compound?" "What can you infer about X from looking at Y?"
   c) output – "If we continue to burn fossil fuels, what will be the effect on agriculture in different parts of the world?" "What would be the best solution to our air pollution problem?"
   [labels from Pizzini et al, TST, December, 1988]

2. **Journaling**

Clough, in his article in Interchange, 1997, recommends that journaling, or lab reporting, during inquiry labs include not only why the students performed each step and what they learned, but also their thoughts and feelings about the overall experience. In post-lab discussion, the teacher should help the students reflect on how theory guided their experimental setup, what counted as a relevant observation and their interpretations of results.

Colburn, TST, November, 2004, states that teachers have the power to shape student experiences during an activity via the kinds of questions asked. Examples of these kinds of questions might include:

- "What sorts of things have you noticed so far?"
- "Tell me about what you're thinking", or "Tell me about what you're thinking when you see [insert observation here]."
- "What do you think would happen if you [insert variable change here]." (Any of these questions could be followed by "How could you find out?")
- "How confident are you in your conclusion?"
  - "What would it take for you to be more confident?"
  - "Why do you think that is?"
  - "How could you explain that?"

Evans, in discussing assessment with relation to a gas laws unit, relates having students write in their journals characteristics of gases they already knew. They then shared these in groups and as a whole class and made a concept map from what the entire class knew. Then they organized their questions. Students then designed experiments to answer their own questions. At the end of the unit, students were assessed on several levels: they submitted their lab write-ups guided by a rubric, they included their journals as part of their lab reports, and they completed a self-evaluation of their learning and lab performance. Evans also had each lab group prepare three questions related to their investigations; she then extracted the students' questions directly from their reports to use as exam questions. [Evans, Carolyn, TST, January 2004]

3. **Whiteboard presentations and Poster sessions**

Erekson describes a method of assessing student understanding of inquiry activities by using whiteboard presentations in addition to formal lab reports. Baumgartner has her classes do independent investigations, and she uses student poster sessions as a mode of assessment, allowing peers to ask questions on individual posters. [Both TST, March 2004] While both of these are time-consuming, a possible variation would be to assign just one lab group to do such a presentation for each of the labs during the semester or year.

4. **Demos for assessment**

Many demos can be turned into inquiry and assessments. Informal assessments can include having students vote on possible outcomes when a variable is modified, having students propose changes to the demo procedure, and having them offer possible explanations of the chemical principles responsible for the phenomena. Demos can also be turned into test questions. For example, in the unit on conservation of mass, light a candle and place it on a balance. Write the subsequent masses on the board and have students describe what they see, how it supports or refutes the law of conservation of mass, and give possible explanations for the discrepant event. Students should be awarded points here for how well they support their statements with experimental evidence, not necessarily if they got the "right" answer. After all, phlogiston was the "right" answer for many years.

5. **Open-ended questioning techniques**

If you want to teach higher order thinking skills, you must assess them accurately. "By their nature, open-ended questions assess writing, conceptual understanding, and thinking skills – especially students' abilities to analyze, to evaluate, and to solve problems." (Freedman, 3)

The following are the steps which Freeedman outlines in chapter 2 of his book:

1. Look over your curriculum to see what concepts or topics lend themselves to open-ended questioning formats.
2. Based on critical thinking skills you wish to assess, choose one questioning format. [See below]
3. Write the first part of the writing prompt – a description of the situation. Title it and include information that will motivate students to write.
4. Write the directions for writing. Be specific. Define the writing style and include specific content and concepts that you want described or explained.
5. Develop a simple rubric.
6. Save the responses to use as benchmarks the next time you use your question.

Questioning formats:

1. *Analysis*: defines something by defining what it is, what it isn't, what it ought to be and what it implies.
2. *Comparison*: How things are similar and how they are different; how things change over time.
3. *Description*: Explains things using the five senses. This includes report of information writing.
4. *Evaluation*: Focuses on supporting evidence and uses the evidence to make a judgment.
5. *Fiction*: Demonstrates the ability to synthesize information to an imaginary context.
6. *Problem-Solving*: A specific kind of analysis. The writer describes and analyzes a specific problem, proposes a solution and tries to convince the reader that the solution is feasible.

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Glossary of Common Scientific Terms

hypothetico-inductive method - the basis of many research disciplines, this approach uses questioning to devise new experiments rather than formal hypotheses.

science - a self-correcting endeavor providing constantly remodeled theories in an attempt to understand nature (Storey, Richard D.)

law - A general verbal statement or mathematical equation that summarizes a wide variety of observations (Nebergall)

theory - A set of assumptions put forth to explain some aspect of the observed behavior of matter. (Zumdahl)

hypothesis - 1. A set of assumptions put forth to explain some aspect of the observed behavior of matter. (Zumdahl), 2. A tentative explanation of physical or chemical phenomena. (Nebergall)

Relevant Quotes

Public understanding of science is more central to our national security than half a dozen strategic weapons systems. ~Carl Sagan

The beginning of teaching should be made by dealing with actual things. The object must be a real, useful thing, capable of making an impression upon the senses… if visible, with the eyes; if audible, with the ears; if tangible, with the touch; if odorous, with the nose; if sapid, with the taste. First the presentation of the thing itself... then the real explanation for the further elucidation of it. ~J. A. Comenius (1592-1670)

The acute problems of the world can be solved only by *whole* men, not by people who refuse to be, publicly, anything more than a technologist, or a pure scientist, or an artist. In the world of today you have got to be everything or you are going to be nothing. ~C.H. Waddington

It would be possible to describe everything scientifically, but it would make no sense; it would be without meaning, as if you described a Beethoven symphony as a variation of wave pressure. ~Albert Einstein