Science as Inquiry

Is This Inquiry or Is It Not?

Inquiry Card Sort

The development of the following materials was supported by the National Science Foundation under Grant No. ESI-9911615, A BSCS Implementation and Dissemination Project for High School Science Education. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the granting agency.

IS THIS INQUIRY OR IS IT NOT?
INQUIRY CARD SET

1. Students discuss a magazine article about the everyday work of scientists.	2. Students formulate evidence-based explanations of scientific phenomena and communicate these explanations to their peers.	3. The teacher helps the students connect consistent patterns in their data to established scientific laws or principles (e.g., Boyle's Law, Ohm's Law).
4. Students design and conduct investigations that are based upon their own questions about scientific phenomena.	5. Students read a case study that describes a debate among scientists where the two competing sides question the evidence and logic of the other (e.g., cold fusion).	6. Students design and conduct investigations that are based upon teacher-generated questions about scientific phenomena.
7. Students analyze and critique each others' explanations of scientific phenomena.	8. The teacher leads a class discussion about procedures that scientists commonly use and the similarities between those procedures and the students' laboratory work.	9. The teacher encourages students to reflect on their understanding of certain biology concepts as they conduct investigations and formulate/revise explanations.

A Case Study of Scientific Inquiry

Beluga Whales

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North America
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ARCTIC OCEAN
Bering Sea
Beaufort Sea
Alaska (U.S.)
Greenland (Denmark)
Baffin Bay
Labrador Sea
Hudson Bay
Canada
Canadian Shield
Great Plains
Rocky Mts.
Coast Ranges
Appalachian Mts.
United States
EUROPE
Arctic Circle
60° N
80° N
0°
40° N
20° W
40° W
20° N
Tropic of Cancer
ATLANTIC OCEAN
Bermuda (U.K.)
0 1,000 Miles
0 1,000 Kilometers
180°
Hawaii (U.S.)
PACIFIC OCEAN
0° Equator
160° W
140° W
120° W
Gulf of Mexico
Mexico
CARIBBEAN
Cuba
Haiti
Puerto Rico (U.S.)
Dominican Republic
Jamaica
Belize
Honduras
Guatemala
El Salvador
Nicaragua
Costa Rica
Panama
SOUTH AMERICA

Passage One

Beluga Whales in the St. Lawrence River

The Arctic beluga whales are, at maturity, pure white and highly intelligent organisms. They have lived in the St. Lawrence Seaway for millennia. As a resource, beluga whales provided traders, fisheries, and settlers with a livelihood for centuries. But, times change. Scientists estimate that the population of belugas must have been 5,000 to 10,000 near the turn of the 20th century and about 500 in the second half of the century. As the demand for whale products decreased, the beluga were increasingly ignored and almost forgotten. One would assume that the populations would increase. However, by the 1970s the population still was estimated at 500. In 1979 the Canadian government provided the whales complete protection from hunting. Despite this twenty-year protection, the population has not increased.

- Why do you think the number of whales has not increased?

- What is the question that would best guide a scientific investigation about why the population of whales does not increase?

Temperature of Mixtures

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Temperature of Mixtures

Purpose

- To predict the final temperature of a mixture of cups of water at different temperatures
- To relate the investigation to the Law of Conservation of Energy

Part I: Thinking About Temperature

If you mix a cup of cold water with a cup of hot water, the temperature of the mixture will be between the two initial temperatures. What information would you need to predict the final temperature? This lab investigates what factors are involved in changes of temperature.

Before actually doing the investigation, imagine a cup full of water at 60°C and a pail full of water at 20°C.

	Circle One	
1. Which do you think is hotter—the water in the cup or in the pail?	cup	pail

Explain your answer.

2. Which do you think has more energy?	cup	pail

Explain your answer.

3. Which would take longer to change its temperature by 10°C if left alone?	cup	pail

Explain your answer.

4. If you put the same amount of red-hot iron into the water in the cup and in the pail, which would show a greater change in temperature?	cup	pail

Explain your answer.

Temperature of Mixtures

Part II: Investigating the Temperature of a Mixture of Equal Measures

Step 1: In the room are two containers filled with water, one with cold water and one with hot water. Fill one cup ¾ full with cold water from the container. Mark the water level along the inside of the cup. Pour the cup's water into a second cup. Mark it as you did the first one. Dispose of the water. Now both cups have marks that show nearly equal measures.

Why don't the marks show exactly equal measures?

Step 2: Fill one cup to the mark with hot water from the container. Fill the second cup to the mark with cold water from the container. Measure and record the temperature of both cups of water.

temperature of hot water = ________ °C

temperature of cold water = ________ °C

Step 3: What will be the temperature if you mix the two cups of water in the liter container? Record your prediction.

predicted temperature of mixture = ________ °C

Step 4: Pour the two cups of water into the liter container, stir the mixture, and measure and record its temperature.

actual temperature of mixture = ________ °C

Step 5: Answer the following questions.

If there was a difference between your prediction and your observation, what might have caused it?
Based on your data, how can you predict, with reasonable accuracy, the final temperature of a mixture of equal amounts of hot and cold water?

Step 6: Pour the mixture into the sink or waste pail. Do not pour it back into either of the containers of cold or hot water!

Temperature of Mixtures

Part III: Investigating the Temperature of a Mixture of Non-equal Measures

Task

1. With the materials provided, design and conduct an investigation that will help you answer the following question:

   How can you predict, with reasonable accuracy, the final temperature of a mixture of unequal amounts of hot and cold water?

   Note: Make sure you test whether or not your explanation works when there is more hot water than cold water added to a mixture and vise versa.

2. Using chart paper, record a detailed description of the following:

   - Your experimental evidence
   - Your evidence-based explanation for how to predict the final temperature. If necessary, provide evidence (data) that will allow you to revise your explanation.
   - Your response to the following questions:
     - What factors affect the temperature of a mixture of hot and cold water?
     - How do you think each of these factors affects the temperature of the mixture?

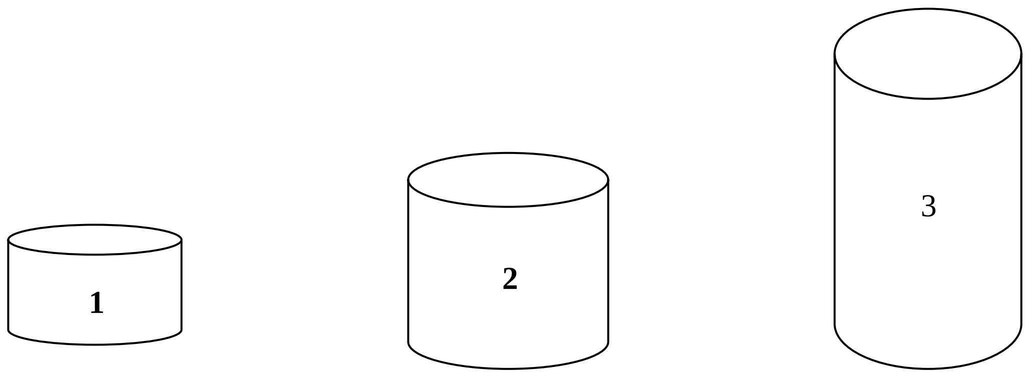
Adapted from: Robinson, P. (1987) Laboratory Manual/Teacher's Edition from *Conceptual Physics: A High School Physics Program* by Paul G. Hewitt. Menlo Park, CA: Addison-Wesley Publishing Company.

Temperature of Mixtures

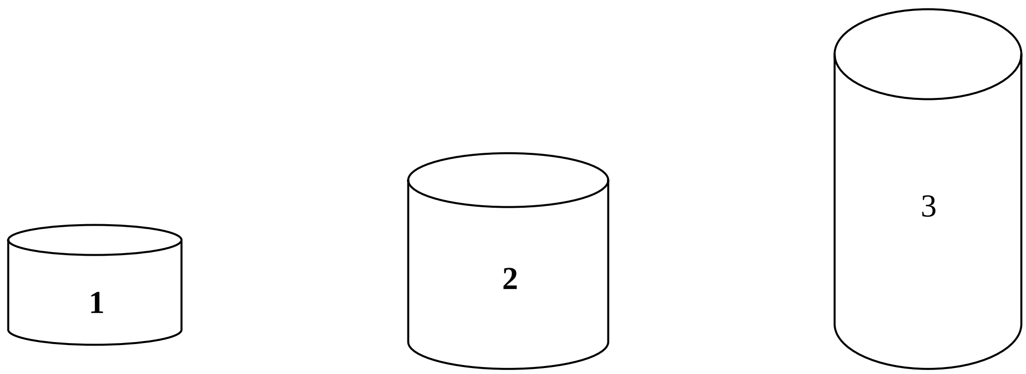
Part V: What Have I Learned about the Temperature of Mixtures?

Use your explanation from Part III for predicting the final temperatures of mixtures to answer the following questions.

1. In Container 3, 1 liter of 30 degree (C) water from Container 1 is mixed with 2 liters of 10 degree (C) water from Container 2. What will be the temperature of the mixture shortly after being mixed? Show your work.



2. In Container 3, 1 liter of 10 degree (C) water from Container 1 is mixed with 2 liters of 30 degree (C) water from Container 2. What will be the temperature of the mixture shortly after being mixed? Show your work.



Scientific Inquiry as a Teaching Strategy

Analysis of Classroom Video

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Essential Features of Classroom Inquiry and Their Variations

FEATURE	Less……Learner Self –Direction……More More……Direction from Teacher or Material……Less			
1. Learner engages in scientifically oriented questions	**A**. Learner engages in question provided by teacher, materials, or other source	**B**. Learner sharpens or clarifies question provided by teacher, materials, or other source	**C**. Learner selects among questions, poses new questions	**D**. Learner poses a question
2. Learner gives priority to evidence in responding to questions	**A**. Learner given data and told how to analyze	**B**. Learner given data and asked to analyze	**C**. Learner directed to collect certain data	**D**. Learner determines what constitutes evidence and collects it
3. Learner formulates explanations from evidence	**A**. Learner provided with evidence	**B**. Learner given possible ways to use evidence to formulate explanation	**C**. Learner guided in process of formulating explanations from evidence	**D**. Learner formulates explanation after summarizing evidence
4. Learner connects explanations to scientific knowledge	**A**. Learner given all connections	**B**. Learner given possible connections	**C**. Learner directed toward areas and sources of scientific knowledge	**D**. Learner independently examines other resources and forms the links to explanations
5. Learner communicates and justifies explanations	**A**. Learner given steps and procedures for communication	**B**. Learner provided broad guidelines to use to sharpen communication	**C**. Learner coached in development of communication	**D**. Learner forms reasonable and logical argument to communicate explanations

Source: National Research Council. 2000. Inquiry and the National Science Education Standards, A Guide for Teaching and Learning. Washington, DC: National Academy Press, P. 29

Video Observation Sheet

As you watch the video segment, focus on what the students and the teacher are doing and how these behaviors might help students develop their understanding of the science content presented in the activity. In the first column below, write specific **student behaviors** that you observe. In the second column, write the **teacher's behaviors** that correspond with the student behaviors. In the third column, write **the purpose of the activity** in the video.

Essential Feature of Inquiry: ____

Video Segment One

What were the students doing?	What was the teacher doing?	What was the purpose of the activity?

Video Segment Two

What were the students doing?	What was the teacher doing?	What was the purpose of the activity?

Video Segment Three

What were the students doing?	What was the teacher doing?	What was the purpose of the activity?

Teaching Elementary School Science

Completing the Circuit

Video Sequence

1: What do I know about electricity?
2: Making a Motor Spin **Recording What Works and What Doesn't Work**
3: Exploring with New Materials
4: Lighting the Bulb Using One Battery, One Wire, and One Bulb **Recording What Works and What Doesn't Work**
5: Lighting the Bulb Using One Battery, Two Wires, and One Bulb **Recording What Works and What Doesn't Work**
6: Developing Explanations of Complete Circuits
7: Designing Parallel and Series Circuits **Recording What Works and What Doesn't Work**
8: Developing Explanations of Parallel and Series Circuits

Teaching Secondary School Science

The Physics of Optics

Video Sequence

1: What do I know about vision?
2: Focusing an image using an overhead projector
3: Making an image with a candle, lens, and piece of paper
4: Deriving an equation for a lens from similar triangles using ray diagrams and knowledge of mirrors
5: Collecting experimental data
6: Graphing experimental data to determine equation of a lens
7: Designing a human eye
8: Presenting a poster of the human eye

National and State Standards

NATIONAL SCIENCE EDUCATION STANDARDS (NSES)

GRADES K-4

SCIENCE AS INQUIRY

CONTENT STANDARD A:

As a result of activities in grades K-4, all students should develop

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY

ASK A QUESTION ABOUT OBJECTS, ORGANISMS, AND EVENTS IN THE ENVIRONMENT. This aspect of the standard emphasizes students asking questions that they can answer with scientific knowledge, combined with their own observations. Students should answer their questions by seeking information from reliable sources of scientific information and from their own observations and investigations.

PLAN AND CONDUCT A SIMPLE INVESTIGATION. In the earliest years, investigations are largely based on systematic observations. As students develop, they may design and conduct simple experiments to answer questions. The idea of a fair test is possible for many students to consider by fourth grade.

EMPLOY SIMPLE EQUIPMENT AND TOOLS TO GATHER DATA AND EXTEND THE SENSES. In early years, students develop simple skills, such as how to observe, measure, cut, connect, switch, turn on and off, pour, hold, tie, and hook. Beginning with simple instruments, students can use rulers to measure the length, height, and depth of objects and materials; thermometers to measure temperature; watches to measure time; beam balances and spring scales to measure weight and force; magnifiers to observe objects and organisms; and microscopes to observe the finer details of plants, animals, rocks, and other materials. Children also develop skills in the use of computers and calculators for conducting investigations.

USE DATA TO CONSTRUCT A REASONABLE EXPLANATION. This aspect of the standard emphasizes the students' thinking as they use data to formulate explanations. Even at the earliest grade levels, students should learn what constitutes evidence and judge the merits or strength of the data and information that will be used to make explanations. After students propose an explanation, they will appeal to the knowledge and evidence they obtained to support their explanations. Students should check their explanations against scientific knowledge, experiences, and observations of others.

COMMUNICATE INVESTIGATIONS AND EXPLANATIONS. Students should begin developing the abilities to communicate, critique, and analyze their work and the work of other students. This communication might be spoken or drawn as well as written.

Source: National Science Education Standards 1996
National Academy Press, Washington, DC

UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

- Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world.
- Scientists use different kinds of investigations depending on the questions they are trying to answer. Types of investigations include describing objects, events, and organisms; classifying them; and doing a fair test (experimenting).
- Simple instruments, such as magnifiers, thermometers, and rulers, provide more information than scientists obtain using only their senses.
- Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge). Good explanations are based on evidence from investigations.
- Scientists make the results of their investigations public; they describe the investigations in ways that enable others to repeat the investigations.
- Scientists review and ask questions about the results of other scientists' work.

Source: National Science Education Standards 1996
National Academy Press**,** Washington, DC

NATIONAL SCIENCE EDUCATION STANDARDS (NSES)
GRADES 5-8

SCIENCE AS INQUIRY

CONTENT STANDARD A:

As a result of activities in grades 5-8, all students should develop

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY

IDENTIFY QUESTIONS THAT CAN BE ANSWERED THROUGH SCIENTIFIC INVESTIGATIONS. Students should develop the ability to refine and refocus broad and ill-defined questions. An important aspect of this ability consists of students' ability to clarify questions and inquiries and direct them toward objects and phenomena that can be described, explained, or predicted by scientific investigations. Students should develop the ability to identify their questions with scientific ideas, concepts, and quantitative relationships that guide investigation.

DESIGN AND CONDUCT A SCIENTIFIC INVESTIGATION. Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables. They should also develop the ability to clarify their ideas that are influencing and guiding the inquiry, and to understand how those ideas compare with current scientific knowledge. Students can learn to formulate questions, design investigations, execute investigations, interpret data, use evidence to generate explanations, propose alternative explanations, and critique explanations and procedures.

USE APPROPRIATE TOOLS AND TECHNIQUES TO GATHER, ANALYZE, AND INTERPRET DATA. The use of tools and techniques, including mathematics, will be guided by the question asked and the investigations students design. The use of computers for the collection, summary, and display of evidence is part of this standard. Students should be able to access, gather, store, retrieve, and organize data, using hardware and software designed for these purposes.

DEVELOP DESCRIPTIONS, EXPLANATIONS, PREDICTIONS, AND MODELS USING EVIDENCE. Students should base their explanation on what they observed, and as they develop cognitive skills, they should be able to differentiate explanation from description—providing causes for effects and establishing relationships based on evidence and logical argument. This standard requires a subject matter knowledge base so the students can effectively conduct investigations, because developing explanations establishes connections between the content of science and the contexts within which students develop new knowledge.

Source: National Science Education Standards 1996
National Academy Press, Washington, DC

THINK CRITICALLY AND LOGICALLY TO MAKE THE RELATIONSHIPS BETWEEN EVIDENCE AND EXPLANATIONS. Thinking critically about evidence includes deciding what evidence should be used and accounting for anomalous data. Specifically, students should be able to review data from a simple experiment, summarize the data, and form a logical argument about the cause-and-effect relationships in the experiment. Students should begin to state some explanations in terms of the relationship between two or more variables.

RECOGNIZE AND ANALYZE ALTERNATIVE EXPLANATIONS AND PREDICTIONS. Students should develop the ability to listen to and respect the explanations proposed by other students. They should remain open to and acknowledge different ideas and explanations, be able to accept the skepticism of others, and consider alternative explanations.

COMMUNICATE SCIENTIFIC PROCEDURES AND EXPLANATIONS. With practice, students should become competent at communicating experimental methods, following instructions, describing observations, summarizing the results of other groups, and telling other students about investigations and explanations.

USE MATHEMATICS IN ALL ASPECTS OF SCIENTIFIC INQUIRY. Mathematics is essential to asking and answering questions about the natural world. Mathematics can be used to ask questions; to gather, organize, and present data; and to structure convincing explanations.

UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

- Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.
- Current scientific knowledge and understanding guide scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding.
- Mathematics is important in all aspects of scientific inquiry.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
- Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories. The scientific community accepts and uses such explanations until displaced by better scientific ones. When such displacement occurs, science advances.
- Science advances through legitimate skepticism. Asking questions and querying other scientists' explanations is part of scientific inquiry. Scientists evaluate the explanations proposed by other scientists by examining evidence, comparing evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations.
- Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data. All of these results can lead to new investigations.

Source: National Science Education Standards 1996
National Academy Press**,** Washington, DC

NATIONAL SCIENCE EDUCATION STANDARDS (NSES)
GRADES 9-12

SCIENCE AS INQUIRY

CONTENT STANDARD A:

As a result of activities in grades 9-12, all students should develop

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY

IDENTIFY QUESTIONS AND CONCEPTS THAT GUIDE SCIENTIFIC INVESTIGATIONS. Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations.

DESIGN AND CONDUCT SCIENTIFIC INVESTIGATIONS. Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations.

USE TECHNOLOGY AND MATHEMATICS TO IMPROVE INVESTIGATIONS AND COMMUNICATIONS. A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results.

FORMULATE AND REVISE SCIENTIFIC EXPLANATIONS AND MODELS USING LOGIC AND EVIDENCE. Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation.

Source: National Science Education Standards 1996
National Academy Press, Washington, DC

RECOGNIZE AND ANALYZE ALTERNATIVE EXPLANATIONS AND MODELS. This aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best. In other words, although there may be several plausible explanations, they do not all have equal weight. Students should be able to use scientific criteria to find the preferred explanations.

COMMUNICATE AND DEFEND A SCIENTIFIC ARGUMENT. Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments.

UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

- Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.
- Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.
- Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.
- Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.
- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.
- Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation.

Source: National Science Education Standards 1996
National Academy Press**,** Washington, DC

NATIONAL SCIENCE EDUCATION STANDARDS (NSES)

Teaching Standard B

Teachers of science guide and facilitate learning. In doing this, teachers

- Focus and support inquiries while interacting with students.
- Orchestrate discourse among students about scientific ideas.
- Challenge students to accept and share responsibility for their own learning.
- Recognize and respond to student diversity and encourage all students to participate fully in science learning.
- Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

Coordinating people, ideas, materials, and the science classroom environment are difficult, continual tasks. This standard focuses on the work that teachers do as they implement the plans of Standard A in the classroom.

At all stages of inquiry, teachers guide, focus, challenge, and encourage student learning.

Teachers of science constantly make decisions, such as when to change the direction of a discussion, how to engage a particular student, when to let a student pursue a particular interest, and how to use an opportunity to model scientific skills and attitudes. Teachers must struggle with the tension between guiding students toward a set of predetermined goals and allowing students to set and meet their own goals. Teachers face a similar tension between taking the time to allow students to pursue an interest in greater depth and the need to move on to new areas to be studied. Furthermore, teachers constantly strike a balance among the demands of the understanding and ability to be acquired and the demands of student-centered developmental learning. The result of making these decisions is the enacted curriculum—the planned curriculum as it is modified and shaped by the interactions of students, teachers, materials, and daily life in the classroom.

FOCUS AND SUPPORT INQUIRIES. Student inquiry in the science classroom encompasses a range of activities. Some activities provide a basis for observation, data collection, reflection, and analysis of firsthand events and phenomena. Other activities encourage the critical analysis of secondary sources—including media, books, and journals in a library.

In successful science classrooms, teachers and students collaborate in the pursuit of ideas, and students quite often initiate new activities related to an inquiry. Students formulate questions and devise ways to answer them, they collect data and decide how to represent it, they organize data to generate knowledge, and they test the reliability of the knowledge they have generated. As they proceed, students explain and justify their work to themselves and to one another, learn to cope with problems such as the limitations of equipment, and react to challenges posed by the teacher and by classmates. Students assess the efficacy of their efforts—they evaluate the data they have collected, re-examining or collecting more if necessary, and making statements about the generalizability of their findings. They plan and make presentations to the rest of the class about their work and accept and react to the constructive criticism of others.

Source: National Science Education Standards 1996
National Academy Press, Washington, DC

At all stages of inquiry, teachers guide, focus, challenge, and encourage student learning. Successful teachers are skilled observers of students, as well as knowledgeable about science and how it is learned. Teachers match their actions to the particular needs of the students, deciding when and how to guide—when to demand more rigorous grappling by the students, when to provide information, when to provide particular tools, and when to connect students with other sources.

In the science classroom envisioned by the *Standards*, effective teachers continually create opportunities that challenge students and promote inquiry by asking questions.

Although open exploration is useful for students when they encounter new materials and phenomena, teachers need to intervene to focus and challenge the students, or the exploration might not lead to understanding. Premature intervention deprives students of the opportunity to confront problems and find solutions, but intervention that occurs too late risks student frustration. Teachers also must decide when to challenge students to make sense of their experiences: At these points, students should be asked to explain, clarify, and critically examine and assess their work.

ORCHESTRATE DISCOURSE AMONG STUDENTS ABOUT SCIENTIFIC IDEAS. An important stage of inquiry and of student science learning is the oral and written discourse that focuses the attention of students on how they know what they know and how their knowledge connects to larger ideas, other domains, and the world beyond the classroom. Teachers directly support and guide this discourse in two ways: They require students to record their work—teaching the necessary skills as appropriate—and they promote many different forms of communication (for example, spoken, written, pictorial, graphic, mathematical, and electronic).

Using a collaborative group structure, teachers encourage interdependency among group members, assisting students to work together in small groups so that all participate in sharing data and in developing group reports. Teachers also give groups opportunities to make presentations of their work and to engage with their classmates in explaining, clarifying, and justifying what they have learned. The teacher's role in these small and larger group interactions is to listen, encourage broad participation, and judge how to guide discussion—determining ideas to follow, ideas to question, information to provide, and connections to make. In the hands of a skilled teacher, such group work leads students to recognize the expertise that different members of the group bring to each endeavor and the greater value of evidence and argument over personality and style.

CHALLENGE STUDENTS TO ACCEPT AND SHARE RESPONSIBILITY FOR THEIR OWN LEARNING. Teachers make it clear that each student must take responsibility for his or her work. The teacher also creates opportunities for students to take responsibility for their own learning, individually and as members of groups.

Teachers do so by supporting student ideas and questions and by encouraging students to pursue them. Teachers give individual students active roles in the design and implementation of investigations, in the preparation and presentation of student work to their peers, and in student assessment of their own work.

Source: National Science Education Standards 1996
National Academy Press, Washington, DC

RECOGNIZE AND RESPOND TO STUDENT DIVERSITY AND ENCOURAGE ALL STUDENTS TO PARTICIPATE FULLY IN SCIENCE LEARNING. In all aspects of science learning as envisioned by the *Standards*, skilled teachers recognize the diversity in their classes and organize the classroom so that all students have the opportunity to participate fully. Teachers monitor the participation of all students, carefully determining, for instance, if all members of a collaborative group are working with materials or if one student is making all the decisions. This monitoring can be particularly important in classes of diverse students, where social issues of status and authority can be a factor.

Teachers who are enthusiastic, interested, and who speak of the power and beauty of scientific understanding instill in their students some of those same attitudes.

Teachers of science orchestrate their classes so that all students have equal opportunities to participate in learning activities. Students with physical disabilities might require modified equipment; students with limited English ability might be encouraged to use their own language as well as English and to use forms of presenting data such as pictures and graphs that require less language proficiency; students with learning disabilities might need more time to complete science activities.

ENCOURAGE AND MODEL THE SKILLS OF SCIENTIFIC INQUIRY, AS WELL AS THE CURIOSITY, OPENNESS TO NEW IDEAS, AND SKEPTICISM THAT CHARACTERIZE SCIENCE. Implementing the recommendations above requires a range of actions based on careful assessments of students, knowledge of science, and a repertoire of science-teaching strategies. One aspect of the teacher's role is less tangible: teachers are models for the students they teach. A teacher who engages in inquiry with students models the skills needed for inquiry. Teachers who exhibit enthusiasm and interest and who speak to the power and beauty of scientific understanding instill in their students some of those same attitudes toward science. Teachers whose actions demonstrate respect for differing ideas, attitudes, and values support a disposition fundamental to science and to science classrooms that also is important in many everyday situations.

The ability of teachers to do all that is required by Standard B requires a sophisticated set of judgments about science, students, learning, and teaching. To develop these judgments, successful teachers must have the opportunity to work with colleagues to discuss, share, and increase their knowledge. They are also more likely to succeed if the fundamental beliefs about students and about learning are shared across their school community in all learning domains. Successful implementation of this vision of science teaching and learning also requires that the school and district provide the necessary resources, including time, science materials, professional development opportunities, appropriate numbers of students per teacher, and appropriate schedules. For example, class periods must be long enough to enable the type of inquiry teaching described here to be achieved.

Source: National Science Education Standards 1996
National Academy Press, Washington, DC

Michigan Department of Education
Science Content Strands, K-12

Overview of the Science Content Strands

Strand I. Constructing New Scientific Knowledge

Scientifically literate students are learners as well as users of knowledge. With scientific literacy comes the ability to ***ask questions*** *about the world that can be answered by using scientific knowledge and techniques. Scientifically literate students can also* ***develop solutions*** *to problems that they encounter or questions they ask. In developing solutions, scientifically literate students may use their own knowledge and reasoning abilities, seek out additional knowledge from other sources, and engage in empirical investigations of the real world. They can learn by* ***interpreting*** *text, graphs, tables, pictures, or other representations of scientific knowledge. Finally, scientifically literate students can remember key points and use sources of information to* ***reconstruct*** *previously learned knowledge, rather than try to remember every detail of what they study.*

Standard I.1 Constructing New Scientific Knowledge
All students will ask questions that help them learn about the world; design and conduct investigations using appropriate methodology and technology; learn from books and other sources of information; communicate their findings using appropriate technology; and reconstruct previously learned knowledge. *There is one standard under Constructing New Scientific Knowledge. This standard incorporates the ways that scientists and individuals investigate and learn about the world.*

Strand II. Reflecting on Scientific Knowledge

Scientifically literate students can also "step back" and analyze or reflect on their own knowledge. One important type of analysis is the ***justification*** *of personal knowledge or beliefs using either theoretically or empirically based arguments. Scientifically literate students can also* ***show an appreciation*** *for scientific knowledge and the patterns that it reveals in the world; this often involves seeing* ***connections*** *among different areas of knowledge. They may be able to take a* ***historical and cultural perspective*** *on concepts and theories or to discuss institutional relationships among* ***science****,* ***technology****, and* ***society****. Finally, scientifically literate students can* ***describe the limitations*** *of their own knowledge and scientific knowledge in general.*

Standard II.1 Reflecting on Scientific Knowledge
All students will analyze claims for their scientific merit and explain how scientists decide what constitutes scientific knowledge; how science is related to other ways of knowing; how science and technology affect our society; and how people of diverse cultures have contributed to and influenced developments in science.

There is one standard under Reflecting on Scientific Knowledge. This standard incorporates the nature of the scientific enterprise, its strengths, limitations, and connections to other ways of knowing.

Source: Michigan Department of Education 2000
http://www.michigan.gov/mde/0,1607,7-140-28753_28760---,00.html

Constructing New Scientific Knowledge (C) I.1

Elementary	Middle School	High School
All students will ask questions that help them learn about the world:		
1. Generate questions about the world based on observation. *Key concepts:* Questions lead to action, including careful observation and testing; questions often begin with "What happens if…?" or "How do these two things differ?" *Real-world contexts:* Any in the sections on Using Scientific Knowledge.	1. Generate scientific questions about the world based on observation. *Key concepts:* Scientific questions can be answered by gathering and analyzing evidence about the world. *Real-world contexts:* Any in the sections on Using Scientific Knowledge.	1. Ask questions that can be investigated empirically. *Key concepts:* Questions often build on existing knowledge. *Real-world contexts:* Any in the sections on Using Scientific Knowledge.
All students will design and conduct investigations using appropriate methodology and technology:		
2. Develop solutions to problems through reasoning, observation, and investigations. *Key concepts:*(K-2) gather information, ask questions, think; (3-5) observe, predict, collect data, draw conclusions, conduct fair tests; prior knowledge. *Real-world contexts:* Any in the sections on Using Scientific Knowledge.	2. Design and conduct scientific investigations. *Key concepts:* The process of scientific investigations—test, fair test, hypothesis, theory, evidence, observations, measurements, data, conclusion. Forms for recording and reporting data—tables, graphs, journals. See C-I.1 m.3 (tools). *Real-world contexts:* Any in the sections on Using Scientific Knowledge; also, recognizing differences between observations and inferences; recording observations and measurements of everyday phenomena.	2. Design and conduct scientific investigations. *Key concepts:* Types of scientific knowledge—hypothesis, theory, observation, conclusion, law, data, generalization. Aspects of field research—hypothesis, design, observations, samples, analysis, conclusion. Aspects of experimental research—hypothesis, design, variable, experimental group, control group, prediction, analysis, conclusion. Investigations are based on questions about the world (see C-I.1 h.1). *Real-world contexts:* Any suggested in Using Scientific Knowledge benchmarks for which students would design and/or conduct investigations.

3. Manipulate simple devices that aid observation and data collection.

   Tools: Various data collection tools suitable for this level, such as hand lenses, wind direction indicators, grids for sampling areas of the sky or landscape.

   Real-world contexts: Any suggested in Using Scientific Knowledge benchmarks for which students would design and/or conduct investigations.

3. Use tools and equipment appropriate to scientific investigations.

   Tools: various data collection tools suitable for this level, including computers.

   Real-world contexts: Any suggested in Using Scientific Knowledge benchmarks for which students would design and/or conduct investigations.

4. Use simple measurement devices to make measurements in scientific investigations.

   Key concepts: Measurement units—milliliters, liters, teaspoon, tablespoon, ounce, cup, millimeter, centimeter, meter, gram.

   Measurement tools: Measuring cups and spoons, measuring tape, scale, thermometer, rulers, graduated cylinders.

   Real-world contexts: Making simple mixtures, such as food, play dough, papier mache; measuring height of a person, weight of a ball.

4. Use metric measurement devices to provide consistency in an investigation.

   Key concepts: Documentation—laboratory instructions. Measurement units—milliliters, liters, millimeter, centimeter, meter, gram.

   Measurement tools: Balancing devices, measuring tape, thermometer, graduated cylinder.

   Real-world contexts: Conducting investigations, following or altering laboratory instructions for mixing chemicals.

3. Recognize and explain the limitations of measuring devices.

   Key concepts: Uncertainty, error, range, tolerances, accuracy, precision.

   Tools: Balance, thermometer, measuring tape, ruler, graduated cylinder, electronic measuring devices.

   Real-world contexts: Experiments that use quantitative data; manufacturing systems where measurements are critical.

All students will learn from books and other sources of information:

5. Develop strategies and skills for information gathering and problem solving.

   Tools: Sources of information, such as reference books, trade books, magazines, web sites, other people's knowledge.

   Real-world contexts: Seeking help from or interviewing peers, adults, experts; using libraries, World Wide Web, CD-ROMs and other computer software, other resources.

5. Use sources of information in support of scientific investigations.

   Tools: Periodicals, reference books, trade books, web sites, computer software; forms for presenting scientific information, such as figures, tables, graphs. See R-II.1 m.1 (evaluate strengths/weaknesses of claims).

   Real-world contexts: Libraries, projects where research is needed.

4. Gather and synthesize information from books and other sources of information.

   Key concepts: Scientific journals, text- and computer-based reference materials.

   Real-world contexts: Libraries, technical reference books, Internet, computer software.

All students will communicate findings of investigations, using appropriate technology.

6. Construct charts and graphs and prepare summaries of observations.

   Key concepts: Increase, decrease, no change, bar graph, data table.

   Tools: Graph paper, rulers, crayons.

   Real-world contexts: Examples of bar charts like those found in a newspaper.

6. Write and follow procedures in the form of step-by-step instructions, formulas, flow diagrams, and sketches.

   Key concepts: Purpose, procedure, observation, conclusion, data.

   Real-world contexts: Listing or creating the directions for completing a task, reporting on investigations.

5. Discuss topics in groups by making clear presentations, restating or summarizing what others have said, asking for clarification or elaboration, taking alternative perspectives, and defending a position.

   Key concepts: Logical argument, summary, clarification, elaboration, alternative perspectives.

   Real-world contexts: Newspaper or magazine articles discussing a topic of social concern.

Reflecting on Scientific Knowledge (R) II.1

Elementary	Middle School	High School

All students will analyze claims for their scientific merit and explain how scientists decide what constitutes scientific knowledge:

Elementary

1. Develop an awareness of the need for evidence in making decisions scientifically.

   Key concepts: (K-2) observations; (3-5) data, evidence, sample, fact, opinion.

   Real-world contexts: Deciding whether an explanation is supported by evidence in simple experiments, or relies on personal opinion.

Middle School

1. Evaluate the strengths and weaknesses of claims, arguments, or data.

   Key concepts: Aspects of arguments such as data, evidence, sampling, alternate explanation, conclusion; inference, observation.

   Real-world contexts: Deciding between alternate explanations or plans for solving problems; evaluating advertising claims or cases made by interest groups; evaluating sources of references.

2. Describe limitations in personal knowledge.

   Key concepts: Recognizing degrees of confidence in ideas or knowledge from different sources, evaluating dates and sources of references.

   Real-world contexts: Any in the sections on Using Scientific Knowledge.

High School

1. Justify plans or explanations on a theoretical or empirical basis.

   Key concepts: Aspects of logical argument, including evidence, fact, opinion, assumptions, claims, conclusions, observations.

   Real-world contexts: Any in the sections on Using Scientific Knowledge.

2. Describe some general limitations of scientific knowledge.

   Key concepts: Understanding of the general limits of science and scientific knowledge as constantly developing human enterprises; recognizing that arguments can have emotive, economic, and political dimensions as well as scientific.

   Real-world contexts: Any in the sections on Using Scientific Knowledge.

All students will show how science is related to other ways of knowing:

Elementary

2. Show how science concepts can be illustrated through creative expression such as language arts and fine arts.

   Key concepts: Poetry, expository work, painting, drawing, music, diagrams, graphs, charts.

   Real-world contexts: Explaining simple experiments using paintings and drawings; describing natural phenomena scientifically and poetically.

Middle School

3. Show how common themes of science, mathematics, and technology apply in real-world contexts.

   Thematic ideas: Systems-subsystems, feedback models, mathematical constancy, scale, conservation, structure, function, adaptation.

   Real-world contexts: Any in the sections on Using Scientific Knowledge.

High School

3. Show how common themes of science, mathematics, and technology apply in real-world contexts.

   Thematic ideas: Systems-subsystems, feedback models, mathematical constancy, scale, conservation, structure, function, adaptation.

   Real-world contexts: Any in the sections on Using Scientific Knowledge.

4. Discuss the historical development of key scientific concepts and principles.

   Key concepts: Historical, political, social, and economic factors influencing the development of science. See *Benchmarks for Science Literacy,* AAAS, Chapter 10.

   Real-world contexts: Historical development of key scientific theories.

All students will show how science and technology affect our society:

3. Describe ways in which technology is used in everyday life.

   Key concepts: Provide faster and farther transportation and communication, organize information and solves problems, save time.

   Real-world contexts: Cars, other machines, radios, telephones, computer games, calculators, appliances, e-mail, the World Wide Web.

4. Describe the advantages and risks of new technologies.

   Key concepts: Risk, benefit, side effect, advantage, disadvantage.

   Real-world contexts: Technological systems for manufacturing, transportation, energy distribution, housing, medicine (such as cloning, genetic engineering).

5. Explain the social and economic advantages and risks of new technology.

   Key concepts: Cost-benefit analysis; See LO h.5 (health technology), PME-IV.1 h.1 (household and agricultural materials, EG-V.1 h.4 (resource use), LEC-III.5 h.6 (effects of urban development and agriculture on ecosystems), EAW-V.3 h.4 (air pollution), EH-V.2 h.2 (water pollution.)

   Real-world contexts: Issues related to new technologies, including ones in health-care, transportation, communications, manufacturing, information and media.

4. Develop an awareness of and sensitivity to the natural world.

   Key concepts: Appreciation of the balance of nature and the effects organisms have on each other, including the effects humans have on the natural world.

   Real-world contexts: Any in the sections on Using Scientific Knowledge appropriate to elementary school.

5. Develop an awareness of and sensitivity to the natural world.

   Key concepts: Appreciation of the balance of nature and the effects organisms have on each other, including the effects humans have on the natural world.

   Real-world contexts: Any in the sections on Using Scientific Knowledge appropriate to middle school.

6. Develop an awareness of and sensitivity to the natural world.

   Key concepts: Appreciation of the balance of nature and the effects organisms have on each other, including the effects humans have on the natural world.

   Real-world contexts: Any in the sections on Using Scientific Knowledge appropriate to high school.

All students will show how people of diverse cultures have contributed to and influenced developments in science:

5. Develop an awareness of contributions made to science by people of diverse backgrounds and cultures.

   Key concepts: Scientific contributions made by people of diverse cultures and backgrounds.

   Real-world contexts: Any in the sections on Using Scientific Knowledge appropriate to this benchmark.

6. Recognize the contributions made in science by cultures and individuals of diverse backgrounds.

   Key concepts: Cultural contributions to science, contributions made by people of diverse backgrounds.

   Real-world contexts: Biographies of minority and female scientists; histories of cultural contributions to science.

7. Describe the historical, political, and social factors affecting developments in science.

   Key concepts: Historical, political, social, and economic factors influencing the development of science.

   Real-world contexts: The development of the sun-centered model of the solar system and political pressures on Galileo; the development of Darwin's theory of evolution by natural selection.

Scientific Inquiry

Students develop scientific habits of mind as they use the processes of scientific inquiry to ask valid questions and to gather and analyze information. They understand how to develop hypotheses and make predictions. They are able to reflect on scientific practices as they develop plans of action to create and evaluate a variety of conclusions. Students are also able to demonstrate the ability to communicate their findings to others.

By the end of the K-2 program:

A. Ask a testable question.
B. Design and conduct a simple investigation to explore a question.
C. Gather and communicate information from careful observations and simple investigation through a variety of methods.

By the end of the 3-5 program:

A. Use appropriate instruments safely to observe, measure and collect data when conducting a scientific investigation.
B. Organize and evaluate observations, measurements and other data to formulate inferences and conclusions.
C. Develop, design and safely conduct scientific investigations and communicate the results.

By the end of the 6-8 program:

A. Explain that there are differing sets of procedures for guiding scientific investigations and procedures are determined by the nature of the investigation, safety considerations and appropriate tools.
B. Analyze and interpret data from scientific investigations using appropriate mathematical skills in order to draw valid conclusions.

By the end of the 9-10 program:

A. Participate in and apply the processes of scientific investigation to create models and to design, conduct, evaluate and communicate the results of these investigations.

By the end of the 11-12 program:

A. Make appropriate choices when designing and participating in scientific investigations by using cognitive and manipulative skills when collecting data and formulating conclusions from the data.

Scientific Ways of Knowing

Students realize that the current body of scientific knowledge must be based on evidence, be predictive, logical, subject to modification and limited to the natural world. This includes demonstrating an understanding that scientific knowledge grows and advances as new evidence is discovered to support or modify existing theories, as well as to encourage the development of new theories. Students are able to reflect on ethical scientific practices and demonstrate an understanding of how the current body of scientific knowledge reflects the historical and cultural contributions of women and men who provide us with a more reliable and comprehensive understanding of the natural world.

By the end of the K-2 program:

A. Recognize that there are different ways to carry out scientific investigations. Realize that investigations can be repeated under the same conditions with similar results and may have different explanations.
B. Recognize the importance of respect for all living things.
C. Recognize that diverse groups of people contribute to our understanding of the natural world.

By the end of the 3-5 program:

A. Distinguish between fact and opinion and explain how ideas and conclusions change as new knowledge is gained.
B. Describe different types of investigations and use results and data from investigations to provide the evidence to support explanations and conclusions.
C. Explain the importance of keeping records of observations and investigations that are accurate and understandable.
D. Explain that men and women of diverse countries and cultures participate in careers in all fields of science.

By the end of the 6-8 program:

A. Use skills of scientific inquiry processes (e.g., hypothesis, record keeping, description and explanation).
B. Explain the importance of reproducibility and reduction of bias in scientific methods.
C. Give examples of how thinking scientifically is helpful in daily life.

By the end of the 9-10 program:

A. Explain that scientific knowledge must be based on evidence, be predictive, logical, subject to modification and limited to the natural world.
B. Explain how scientific inquiry is guided by knowledge, observations, ideas and questions.
C. Describe the ethical practices and guidelines in which science operates.
D. Recognize that scientific literacy is part of being a knowledgeable citizen.

By the end of the 11-12 program:

A. Explain how scientific evidence is used to develop and revise scientific predictions, ideas or theories.
B. Explain how ethical considerations shape scientific endeavors.
C. Explain how societal issues and considerations affect the progress of science and technology.

References

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