1 Essential #1: Inquiry-Based Science Develops an Understanding of Basic Concepts

UNDERSTANDING BIG IDEAS IN THE CURRICULUM

What are some ways inquiry-based activities address the “big ideas” and concepts and principles of science? In national and state standards projects, basic concepts of science are clustered under “big ideas.” Specifically, these are called *unifying concepts and processes* in the National Science Education Standards (NSES; National Research Council, 1996) and *themes* in the Benchmarks for Science Literacy (AAAS, 1993). The big ideas of science provide a structure on which knowledge can be built. They cross disciplines and provide an important mental framework for storing knowledge and showing relationships between the disciplines, a key factor for understanding.

Review the basic *themes* of the Benchmarks for Science Literacy:

- *Systems:* A complex interaction of parts that compose a whole. The term implies detailed attention to inputs and outputs or to interactions among the components of a system. The theme also refers to the ability to think about a whole in terms of its parts and to think of parts in terms of how they relate to one another.

- *Models:* Models are tentative, human created schemes or structures that correspond to real objects, systems, events, or natural phenomena. Physical, mathematical, and conceptual models are tools for learning about the objects and events they resemble, especially when the actual things are readily available or visible.

- *Constancy and Change:* Constancy refers to anything that does not change, such as symmetry or the earth's rotation and revolution. Change is a process of something becoming different over time. Much of science and math has to do with understanding how change occurs in nature and in social and technological systems. Small changes in a system at one point in time may produce very large changes later.

- *Scale:* Most variables in nature such as size, distance, weight, and temperature show immense differences. Three very important notions related to scale are the immense size of the universe, the minute size of molecules, and the age of the earth and the life on it.

The Organizational Framework for Science Curriculum in Figure 1.1 shows the way science education standards at the national, state, district, and classroom levels are linked.

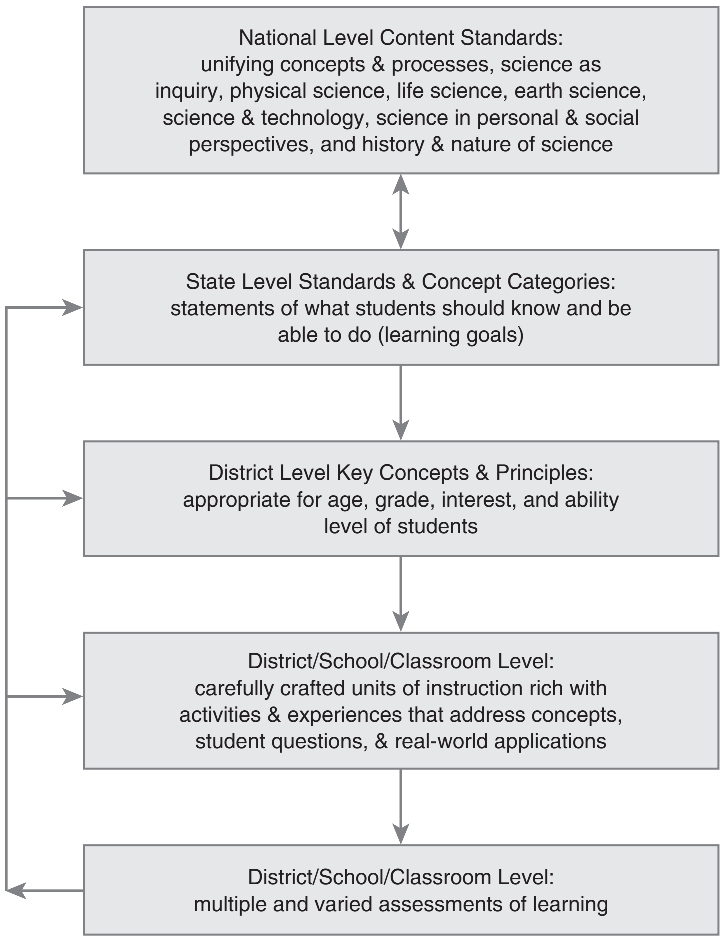
Review the *unifying concepts and processes* of the National Science Education Standards:

- *Systems, Order, and Organization:* A system is an organized group of related objects or components that form a whole. Systems have boundaries, components, resources, flow, and feedback. They are the largest collections of objects used for purposes of describing, predicting, or explaining. Order and organization may take the form of classification systems, grouping patterns, predictable sequences, or stages in a process.

- *Evidence, Models, and Explanation:* Evidence consists of observations and data on which scientific explanations are based. Models are schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations. They may change over time as new information is discovered. Explanations are logical statements that incorporate scientific knowledge and evidence obtained from observations, experiments, or models.

- *Change, Constancy, and Measurement:* Although most things are in the process of change, some properties of objects and processes are characterized by constancy, including the speed of light, the charge of an electron, or the total mass and energy in the universe. Changes occur in properties of materials, position of objects, motion, and form and function of systems. Changes in trends and cycles vary in rate, scale, and pattern.

Figure 1.1 Organizational Framework for Science Curriculum

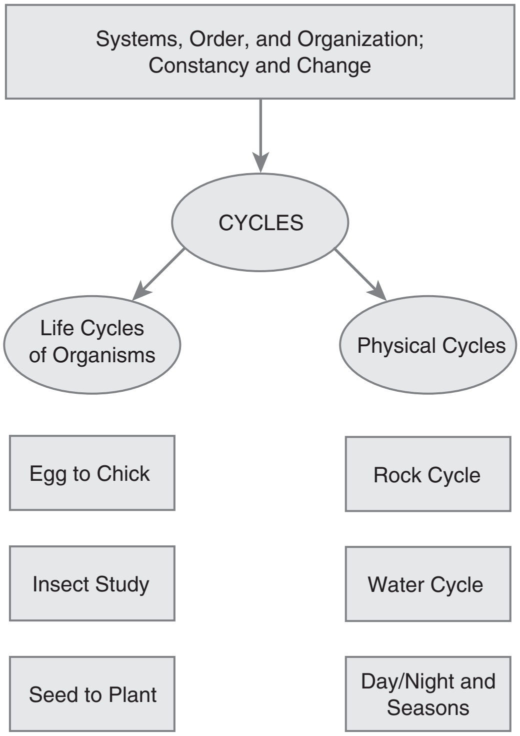


Measurement provides a quantitative method for describing constancy and change.

- *Evolution and Equilibrium:* Evolution is a series of changes, some gradual and some sporadic, that accounts for the present form and function of objects, organisms, and natural and designed systems. Equilibrium is a physical state of balance between opposing forces.

- *Form and Function:* Form and function are complementary aspects of objects, organisms, and systems in the natural and designed world. The form of an object or system is usually related to use, operation, or function.

Figure 1.2 Topics in Elementary Science Linked to Big Ideas



Thought and Reflection

Review your state or district curriculum standards:

1. Are big ideas included in the documents? If so, identify them and explain how they are used to structure the content of science,
2. What are the expectations for learning with regard to the big ideas?

Thought and Discussion

An example of the relationship of big ideas to concept categories and topics in life and physical science is shown in Figure 1.2.

1. Discuss how each topic addresses the big idea of cycles and one or more of the others.
2. What are the common factors in the topics that allow them to be clustered under the headings?
3. What is necessary for students to be able to identify and describe the relationships between the topics?

Figure 1.3 NSES Content Standards for Life, Earth and Space, and Physical Science

Early Elementary	*Middle/Upper Elementary*
Properties of objects and materials	Properties and changes of properties in matter
Position and motion of objects	Motion and forces
Light, heat, electricity, and magnetism	Transfer of energy
Characteristics of organisms	Characteristics of organisms
Life cycles of organisms	Structure and function in living systems
Organisms and environments	Reproduction and heredity
Properties of earth materials	Regulation and behavior
Objects in the sky	Populations and ecosystems
Changes in Earth and sky	Diversity and adaptations of organisms
	Structure of the earth system
	Earth's history
	Earth and the solar system

Standards as Concept Categories

Besides addressing content standards for life, earth and space, and physical science, national and state standards address the history and nature of science, science as inquiry, science and technology, and science in personal and social perspectives. The standards documents do not always identify the contexts (topics, instructional experiences, use of resources, strategies, etc.) for learning. Those decisions are left to the curriculum developer or classroom teacher.

Figure 1.3 shows the categories of content standards for life science, earth and space science, and physical science for the early elementary and middle/upper elementary grades. These content categories are found in many state documents and science programs and provide a framework for K-8 science education.

Thought and Discussion

Option 1: Select any one or more of the concept categories listed under early elementary or middle/upper elementary and give examples of topics that may be used to address the concept category.

Option 2: Make a list of the science topics that are taught at your grade level and classify them by content categories.

How does a list of concept categories or standards help to inform the design and development of curriculum? What are the strengths and limitations of this approach to curriculum development?

Using Standards to Inform Curriculum and Instruction

For each of the standards or concept categories there is a set of fundamental concepts and principles that provide a more accurate description of what students should know and be able to do related to that standard. Standards, along with their concepts and principles, provide direction for the development of standards-based units of instruction, since they identify what students should know and be able to do with relation to the concept category. Based on these or similar clear targets, instructional activities and experiences can be selected or designed to meet goals, thus providing an instructional program that is aligned with standards. Classroom assessments can be embedded into the instructional program to monitor and guide the learning process and to determine the degree to which goals were met.

Example #1: K-4 Earth and Space Science—Standard: *Objects in the Sky*

NSES concepts and processes:

- The sun, moon, stars, clouds, birds, and airplanes all have properties, locations, and movements that can be observed and described.
- The sun provides the light and heat necessary to maintain the temperature of the earth.

Classroom Applications for the Objects in the Sky *Standard:*

Engagement: Begin by asking students what the sun, moon, stars, clouds, birds, and airplanes have in common. Determine what students know about these objects in the sky; ask what they would like to know about objects in the sky. Identify inquiry questions and allow students to suggest ways they would like to study objects in the sky.

Exploration: Take students outdoors to make observations of clouds, birds, airplanes. Ask them to describe what these objects in the sky have in common. Describe and demonstrate motion of objects in the sky and changes in objects over time.

Figure 1.4 Activities and Assessments for Sample Units

Sample Unit Titles	Sample Activities That Address Key Concepts	Sample Assessments
A Study of Shadows	Study shadows and changes in shadow sizes and locations over time. Describe the role of the sun in creating shadows. Observe changes in light and heat in the direct sun and in shady areas throughout a day. Gather data and describe the changes in heat on various surfaces throughout the day: blacktop, cement, soil or grass, buildings, etc.	Describe properties of objects in the sky. Describe the movements of objects in the sky. Explain changes in shadows over time. Notebook entries with data and explanations about properties of objects and movements of objects. Data and explanations to show the effects of sunlight on the earth.
Phases of the Moon	Students may observe the changes in phases of the moon by observing it over a period of time as part of an introduction to the earth-moon-sun system.	Notebook entries and drawings of the moon over time. Describe properties of the moon at various phases. Describe changes in the moon in a month. Demonstrate or explain what causes these changes.
Clouds and Weather	Make observations and record movement of clouds. The formation & movement of clouds may be studied during a unit on weather. Record differences in temperature with and without clouds.	Describe properties of clouds and their movement in the sky. Describe types of clouds and associated weather. Notebook entries. Describe the differences in temperature and light with and without clouds.
Birds, Insects, and Other Things That Fly	When studying birds or insects as groups of animals, observe and describe properties that make it possible for them to fly. Study feathers and wings with magnifiers and draw the structures. Note unusual features; note shapes of birds and their wings and insects and their wings. Observe flight patterns and compare flight of birds with flight of airplanes and gliders. Include concepts related to aerodynamics–gravity, lift, air pressure, and others as appropriate.	Describe and compare objects in the sky. What are the unique properties of birds and insects that enable them to fly? How are birds and insects similar to other objects in the sky? How are birds and insects different from other objects in the sky?

Use a lesson plan format, such as the modified Five E's format (Engagement, Exploration, Explanation, Evaluation, Extension, and sometimes Elaboration) that will be modeled throughout this book, to carefully craft thoughtful, engaging experiences.

Concepts and principles can be studied through any one of a number of instructional topics. To get the most from instructional time, it is important to design and construct units of instruction that address multiple concepts and principles and standards.

Sample classroom applications with ideas for activities and assessments for concepts and principles for two content categories are shown for K-4 *Objects in the Sky* (Figure 1.4) and for K-8 *Structure of the Earth System* (Figures 1.5 and 1.6).

Example #2: **Grades 5–8 Earth and Space Science—Standard: *Structure of the Earth System***

NSES concepts and processes: There are 11 concepts and processes clustered under this standard. Two of the key concepts from the *Structure of the Earth System* standard are:

- Soil consists of weathered rocks and decomposed organic material from dead plants, animals, and bacteria. Soils are often found in layers, with each having a different chemical composition and texture.
- Water, which covers the majority of the earth's surface, circulates through the crust, oceans, and atmosphere in what is known as the *water cycle*. Water evaporates from the earth's surface, rises, and cools as it moves to higher elevations, condenses as rain or snow, and falls to the surface where it collects in lakes, oceans, soil, and in rocks underground.

Classroom Applications for the Structure of the Earth System *Standard*

The concepts for soil and water offer the teacher clues to content information and skills that will provide students with a basic understanding of these topics and enable them to build on their knowledge base. Related topics, such as landforms, and other features of the earth's crust might be dealt with separately, but, for efficiency, they may be clustered, along with important concepts, into units of instruction focusing on the lithosphere or the hydrosphere.

Figure 1.5 Activities and Assessments for a Unit on Soil Science

Sample Unit Titles	*Sample Activities that Address Key Concepts*	*Sample Assessments*
Soil Science (as part of a larger unit on the lithosphere)	Observe similarities and differences in the soils found outdoors. Observe and draw soil profiles.	Describe the composition of soil (organic and inorganic components).
	Take samples of soil and separate components. Observe and describe the similarities and differences in the compositions of soils.	Explain and show evidence that soils in different layers have different chemical compositions and textures.
	Use test kits and tools to determine pH and properties of soils from different layers. Compare soils from different areas.	Notebook entries and projects.
	Use notebooks to record observations and drawings, describe activities and data, and make conclusions; record key concepts and learning.	

Soil Study

Engagement: Begin by asking students what they know about soil. What is it made of? Does soil change as you dig into the earth? Why is soil an important factor in plant growth? Identify misconceptions students have about soil and generate inquiry questions about what they would like to know. (Other creative ways might be used to engage students such as reading a letter inviting them to be a part of a team that is assembled by the U. S. Geologic Survey to investigate soils in their area.)

Exploration: Take students outdoors to make observations of soil. Use a soil sampler or dig down about a foot deep to get a cross section of soil. Record observations. Collect soil samples from a variety of locations, if possible: field, forest, stream, hillside, etc., for comparison. Put each sample into a small plastic bag and label with date and location.

Design a set of age-appropriate activities using samples to investigate properties, conduct tests, make comparisons, and investigate student inquiry questions.

Water Study

Engagement: Ask students what is meant by the statement: "Water, water, everywhere, but not a drop to drink." Discuss fresh versus salt water and

Figure 1.6 Activities and Assessments for a Unit on Water

Sample Unit Titles	*Sample Activities that Address Key Concepts*	*Sample Assessments*
The Wonderful World of Water (as part of a larger unit on the hydrosphere)	Use a world globe to estimate and calculate the percentage of the earth's surface that is covered by water. Compare evaporation of water from open and closed containers. Observe the formation of condensation in a closed terrarium or simulated water cycle in a baggie. Describe factors that influence: Rates of evaporation and condensation; Types of precipitation; Movement of water on the earth; Ability of water to permeate soil and rocks. Trace the flow of water through the water cycle. Explain the process. Use a notebook to record observations, activities and data, and notes and drawings; record conclusions and key concepts learned.	Draw and explain the water cycle. Describe the role of heat energy in the functioning of the water cycle. Notebook entries related to the cycling of water through the earth and atmosphere.

determine what students know about the distribution of water on the earth. Identify misconceptions students have about water and generate inquiry questions about what they would like to know.

Exploration: Design a set of age-appropriate activities to investigate the distribution of water on the earth, properties of water, the water cycle, and the sun as the source of energy for the water cycle.

USING ACTIVITIES TO ENGAGE LEARNERS AND PROMOTE INQUIRY

This time-tested activity *How Many Drops?* is an example of one way an activity or experience can be used to introduce a concept and prompt students to ask questions about what they don't know, that is, to cause them to wonder and to generate questions that lead to further inquiry. The activity also provides a basis for a discussion of ways that activities can engage learners, visually display concepts, promote discussion, and lead to new questions.

Overview: The activity will address the questions: How many drops of water can the heads side of a penny hold? What property of water allows it to accumulate on a penny?

The activity introduces an important property of water, promotes discussion of variables, identifies observations and inferences, and provides the stimulus for students to ask inquiry questions about properties of water.

Materials: Per person: small cup of water; eyedropper; paper towel; penny.

Engagement

Prediction: How many drops of water will the heads side of the penny hold? I think the penny will hold ___drops of water.

Exploration

Place a paper towel on the table; place a penny on the towel. Use an eyedropper to carefully place drops of water on the heads side of the penny. Continue to add drops until the water moves off the penny. Count carefully. Conduct three tests. Record data on the chart and find the average number of drops for the three trials. Describe and make a drawing of your observations.

Explanation

Questions for Discussion:

1. Did everyone get the same number of drops on their pennies? Should they? If so, why do you think they were similar? If not, why do you think they were different?
2. What are variables? Were the eyedroppers the same? Did every person squeeze the bulb the same way and with the same amount of force? Were all the pennies the same?
3. How can you make comparisons among outcomes where the equipment and procedures vary?
4. Describe your observations of the water on the penny. Were you surprised at what you observed? Have you ever seen water behave the way it did in this investigation? When or where?

Figure 1.7 Data Table and Observations

How Many Drops? Data Observation Sheet

Trial #	Number of Drops
1	
2	
3	
Total:	
Average # of drops	

Drawing of Observation:

Observations:

Explanation:

5. Do you know the name of the property of water you discovered? The property is called *surface tension*. Read Paul Hewitt's definition of surface tension below and compare your observations to the definition.

> Surface tension is the contractive force of the surface of liquids.
>
> Surface tension accounts for the spherical shape of liquid drops. Raindrops, oil drops, and drops of molten metal are all spherical because their surfaces tend to contract and force each drop into the shape having the least surface. This is a sphere, for a sphere is the geometrical figure that has the least surface for a given volume.
>
> Surface tension results from the contraction of liquid surfaces which is caused by molecular attractions. Beneath the surface, each molecule is attracted in every direction by neighboring molecules, with the result that the surface of a liquid is pulled only by neighbors to each side and downward from below; there is not a pull upward. These molecular attractions tend to pull the molecule from the surface into the liquid. This tendency to pull surface molecules into the liquid causes the surface to become as small as possible. The surface behaves as if it were tightened into elastic film. Surface tension of water is greater than that of other common liquids. (Hewitt, 1989, pp. 223–224)

Elaboration

Extensions:

1. Based on your experience, how many drops of water do you think the tails side of the penny will hold? Will it be more or less than what you predicted for the heads side? Why?

2. Test other liquids, such as alcohol, soapy water, and salt water for surface tension and compare them to tap water.

New Questions:

1. Now that you have seen what surface tension looks like, what would you like to know about this property of water?

2. Use the definition from Paul Hewitt, if necessary, to develop a set of inquiry questions about surface tension.

3. Add questions about other properties of water that you would like to investigate or research.

Evaluation

1. Write a definition for surface tension based on your experience and support it with the data you collected.
2. Identify notebook entries that show understanding of concept and reflection skills.

Teacher Analysis of the Activity

1. What characteristics does the *How Many Drops* activity have that might make it a good opener for a unit on water?
2. How does the activity address one or more of the big ideas of science?
3. How does the activity demonstrate a concept? Use the definition given from Hewitt's physics book to write a definition for surface tension for your grade level.
4. In what ways does the activity prompt questions? How can you use student-generated questions about surface tension and properties of water to inform instruction?
5. Give an example of one or more activities or experiences that you use (or have seen used) that directly address a concept or principle of science.

Revisit the Original Question

What are some ways inquiry-based activities address the big ideas and concepts and principles of science?