

# Scientific Inquiry and Science Content Standards

The content standards are a complete set of outcomes for students that describe what students should know, understand, and be able to do in natural science. They were designed and developed by the governing board of the National Research Council (NRC) as a comprehensive vision of science education in the U.S. The NRC presented its report, the *National Science Education Standards (1996)*, as an outline for achieving the vision of a scientifically literate nation. These standards are suggested to be most effective when implemented in all aspects of science education including content, teaching, professional development, and assessment.

The eight categories of content standards are

- Unifying concepts and processes in science.
- Science as inquiry.
- Physical science.
- Life science.
- Earth and space science.
- Science and technology.
- Science in personal and social perspectives.
- History and nature of science.

In the vision presented by the *National Science Education Standards (1996)*, inquiry is explained as a step beyond "science as a process," in which students learn skills, such as observation, inference, and experimentation. This new vision requires

students to combine processes and scientific knowledge as they use scientific reasoning and critical thinking to develop their understanding of science. The *National Science Education Standards* defines scientific inquiry as “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.” Developing the ability to understand and engage in this kind of activity requires direct experience and continued practice with the processes of inquiry. Students do not come to understand inquiry simply by learning words such as "hypothesis" and "inference" or by memorizing procedures such as "the steps of the scientific method." They must experience inquiry directly to gain a deep understanding of its characteristics. Engaging students in inquiry helps students develop

- Understanding of scientific concepts.
- An appreciation of "how we know" what we know in science.
- Understanding of the nature of science.
- Skills necessary to become independent inquirers about the natural world.
- The dispositions to use the skills, abilities, and attitudes associated with science.

According to the inquiry standards, students at all grade levels and in every area of science should have the opportunity to use scientific inquiry and develop the ability to ask questions, plan and conduct investigations, use appropriate tools and techniques to gather data, think critically and logically about relationships between evidence and explanations, construct and analyze alternative explanations, and communicate scientific

arguments. From the earliest grades, students should engage in scientific inquiry and enhance their opportunities to develop the abilities of doing science, albeit within their developmental capabilities. In elementary grades, students begin to develop the physical and intellectual abilities of scientific inquiry. For example, they can design investigations to try things to see what happens. Children in K-4 have difficulty with the notion of testing ideas, an abstract concept, and with the formulating of logical explanations based on evidence; therefore, elementary students will benefit more by engaging in partial inquiries. On the other hand, students in grades 5-8 should be provided opportunities to engage in full inquiries. In a full inquiry, students begin with a question, design an investigation, gather evidence, formulate an answer to the original question, and communicate the investigative process and results. In partial inquiries, they develop abilities and engage in selected aspects of the inquiry process and are not required to begin from scratch. Middle school students can begin to recognize the relationship between explanation and evidence and can develop the skills of investigation and the understanding that scientific inquiry is guided by knowledge, observations, ideas, and questions. These students should therefore produce oral or written reports that present the results of their inquiries. Students in grades 5-8 may have some difficulties identifying variables and controlling more than one variable in an experiment, and they tend to propose explanations based on prior beliefs rather than explanations based on evidence collected and logic. These issues may continue to be troubling to students in grades 9-12, but students in these grades should overall be confident in their abilities and understanding of scientific inquiry (NRC, 1996).

**TABLE 6.1. SCIENCE AS INQUIRY STANDARDS**

<b>LEVELS K-4</b>	<b>LEVELS 5-8</b>	<b>LEVELS 9-12</b>
Abilities necessary to do scientific inquiry	Abilities necessary to do scientific inquiry	Abilities necessary to do scientific inquiry
Understanding about scientific inquiry	Understanding about scientific inquiry	Understanding about scientific inquiry

See Appendix A for details (NSES, 1996)

## Teaching Scientific Inquiry

Inquiry is at the heart of the *National Science Education Standards*, enabling teachers to build on children's natural curiosity and human inquisitiveness. In this way, teachers can help all their students understand science as a human endeavor, acquire the scientific knowledge and thinking skills important in everyday life and, if their students so choose, in pursuing a scientific career. But, before 1900, most science educators viewed science mainly as a collection of facts that students were to learn via direct instruction. A major criticism of this point of view came in 1909, when John Dewey, in an address to the American Association for the Advancement of Science, determined that science teaching gave too much emphasis to the accumulation of information and not enough to science as a way of thinking and an attitude of mind. He realized that science was more than a body of knowledge to be learned and that there was a process or method to learn as well (Dewey, 1910).

By the 1950s and 1960s, the argument for inquiry as an approach to teaching science was becoming increasingly apparent in the classroom. The educator Joseph

Schwab was an influential voice in establishing this view of science education. Schwab argued that science should be viewed as conceptual structures that were revised as the result of new evidence (Schwab, 1960, 1966).

Those involved in developing national standards were dedicated to including inquiry as both science content and knowledge as a way to think and learn science. Instead of only promoting "hands-on" or "laboratory based" teaching as the way to teach "science content and process," the writers of the *Standards* adopted inquiry as both a learning goal and as a teaching method. The concept of inquiry thus appears in several different places in the *Standards* including content and teaching. Inquiry teaching and learning have five essential features that may vary in the degree and form of implementation but apply across all grade levels (NCR, 2000).

**Table 2-5. Essential Features of Classroom Inquiry**

- Learners are engaged by scientifically oriented questions.
- Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate **explanations** from evidence to address scientifically oriented questions.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
- Learners communicate and justify their proposed explanations.

Science teachers implementing inquiry in the classroom should also note the following:

*Myth 1: All science subject matter should be taught through inquiry.* Teaching science effectively requires a variety of approaches and strategies. Teaching all of science using only one method would be ineffective, and it would probably become boring for students.

*Myth 2: True inquiry occurs only when students generate and pursue their own questions.* For students to develop the ability to ask questions, they must "practice" asking questions. But if the desired outcome is learning science subject matter, the source of the question is less important than the nature of the question itself.

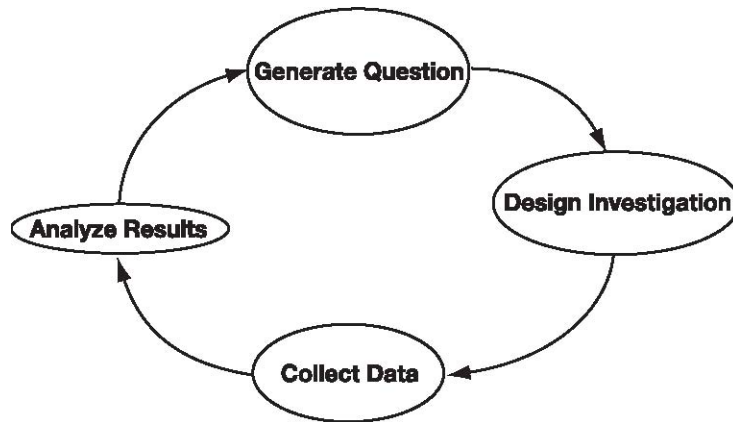
*Myth 3: Inquiry teaching occurs easily through use of hands-on or kit-based instructional materials.* These materials can increase the probability that students' thinking will be focused on the right things and learning will occur in the right sequence. However, the use of even the best materials does not guarantee that students are engaged in rich inquiry, and the teacher must pay careful attention to whether and how the materials incorporate the five essential features of inquiry.

*Myth 4: Student engagement in hands-on activities guarantees that inquiry teaching and learning are occurring.* Although participation by students in activities is desirable, it is not sufficient to guarantee their mental engagement in any of the essential features of inquiry.

*Myth 5: Inquiry can be taught without attention to subject matter.* Students start from what they know and inquire into things they do not know. If, in some instances, a teacher's desired outcome is that students learn to conduct an inquiry, science subject matter serves as a means to that end, and scientific knowledge remains important. The

abilities and understandings outlined in the *Standards* extend beyond the processes of science to engage students in both thinking and learning science (NRC 2000)

## Science Fair and Scientific Inquiry



The four basic steps of scientific inquiry  
(National Science Education Standards, 1996)

Students that complete a science fair project are using the steps of scientific inquiry and are learning science in a most empowering way. For students, the rewards of completing a self-initiated project are great. Students who may never have been successful in science before will show an eagerness and enthusiasm when involved in their own research project and in playing the role of real scientists. What could be more motivating to students? Their self-esteem and self-discipline will improve, and they may discover a whole new world of science, technology, or engineering and be motivated to seek out science experiences beyond the classroom. In addition, going to a fair teaches lessons in sportsmanship and gives students a taste of the collegial nature of science. Chances are, a first-time participant will be highly motivated to participate

in other fairs. Completing a science fair project is also an interdisciplinary endeavor that utilizes a multitude of skills including reading, organizing, synthesizing, calculating, graphing, analyzing, summarizing, and communicating both visually and orally and in writing. For the school, participation in the Regional Fair and a school fair can foster good publicity by getting the community involved in the process. Local science professionals are asked to volunteer in judging students, and they also have the opportunity to coach students with their projects. The result is the cooperation of the school and the community in an activity that empowers its future leaders (Intel, 2000).

Notes on the 4 Step Inquiry Model  
(Intel 2000)

The student Develops an inquiry question	The student Designs an Investigation	The student Gathers and transforms data	The student Prepares an analysis
Do Background Research	Write Clear Procedures	Plan Data Records	Identify patterns in results accurately.
What is an “Inquiry Question”	State Protocols (rules for repeatability and dealing with anomalies.)	Do a transformation that helps answer the question	Explicitly use results to answer the question
Use Operational Definitions (Clarifying the question)	Use concept of “fair test”		Discuss sources of error and limitations
A great question foreshadows a good design	A great design leads to easy data gathering	A great data presentation makes the analysis leap out	

Inquiry into the natural world takes a wide variety of forms. It can range from a child's wondering how it is possible for ants to live underground to the search by groups of physicists for new atomic particles. Inquiry in classrooms also takes a wide variety of forms, as described later in this volume. But whatever its exact form, its role in education is becoming an increasing focus of attention. Today the world is being profoundly influenced by scientific discoveries. People need to make and evaluate decisions that require careful questioning, seeking of evidence, and critical reasoning. Learning environments that concentrate on conveying to students what scientists already know do not promote inquiry. Rather, an emphasis on inquiry asks that we think about what we know, why we know, and how we have come to know.

APPENDIX A – GUIDE TO THE CONTENT STANDARD: SCIENTIFIC INQUIRY  
(NRC, 2000)

**Table 2-2. Content Standard for Science as Inquiry: Fundamental Abilities  
Necessary to Do Scientific Inquiry**

**Grades K-4**

- Ask a question about objects, organisms, and events in the environment.
- Plan and conduct a simple investigation.
- Employ simple equipment and tools to gather data and extend the senses.
- Use data to construct a reasonable explanation.
- Communicate investigations and explanations.

**Grades 5–8**

- Identify questions that can be answered through scientific investigations.
- Design and conduct a scientific investigation.
- Use appropriate tools and techniques to gather, analyze, and interpret data.
- Develop descriptions, explanations, predictions, and models using evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.
- Communicate scientific procedures and explanations.
- Use mathematics in all aspects of scientific inquiry.

**Grades 9–12**

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.

- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Communicate and defend a scientific argument.

**Table 2-3. Content Standard for Science as Inquiry: Fundamental Understandings about Scientific Inquiry**

**Grades K-4**

- 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.
- 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).
- 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.

**Grades 5–8**

- Different kinds of questions suggest different kinds of scientific investigations.
- Current scientific knowledge and understanding guide scientific investigations.
- 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.
- Science advances through legitimate skepticism.

- Scientific investigation 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.

### **Grades 9–12**

- Scientists usually inquire how physical, living, or designed systems function.
- Scientists conduct investigations for a wide variety of reasons.
- Scientists rely on technology to enhance the gathering and manipulation of data.
- Mathematics is essential in scientific inquiry.
- 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 an 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.

APPENDIX B

**ILLINOIS LEARNING STANDARDS – SCIENTIFIC INQUIRY**

**STATE GOAL 11: Understand the processes of scientific inquiry and technological design to investigate questions, conduct experiments and solve problems.**

**Why This Goal Is Important:** The inquiry process prepares learners to engage in science and apply methods of technological design. This understanding will enable students to pose questions, use models to enhance understanding, make predictions, gather and work with data, use appropriate measurement methods, analyze results, draw conclusions based on evidence, communicate their methods and results, and think about the implications of scientific research and technological problem solving.

**A. Know and apply the concepts, principles and processes of scientific inquiry.**

EARLY ELEMENTARY	LATE ELEMENTARY	MIDDLE/JUNIOR HIGH SCHOOL	EARLY HIGH SCHOOL	LATE HIGH SCHOOL
<b>11.A.1a</b> Describe an observed event.	<b>11.A.2a</b> Formulate questions on a specific science topic and choose the steps needed to answer the questions.	<b>11.A.3a</b> Formulate hypotheses that can be tested by collecting data.	<b>11.A.4a</b> Formulate hypotheses referencing prior research and knowledge.	<b>11.A.5a</b> Formulate hypotheses referencing prior research and knowledge.
<b>11.A.1b</b> Develop questions on scientific topics.	<b>11.A.2b</b> Collect data for investigations using scientific process skills including observing, estimating and measuring.	<b>11.A.3b</b> Conduct scientific experiments that control all but one variable.	<b>11.A.4b</b> Conduct controlled experiments or simulations to test hypotheses.	<b>11.A.5b</b> Design procedures to test the selected hypotheses.
<b>11.A.1c</b> Collect data for investigations using measuring instruments and technologies.	<b>11.A.2c</b> Construct charts and visualizations to display data.	<b>11.A.3c</b> Collect and record data accurately using consistent measuring and recording techniques and media.	<b>11.A.4c</b> Collect, organize and analyze data accurately and precisely.	<b>11.A.5c</b> Conduct systematic controlled experiments to test the selected hypotheses.
<b>11.A.1d</b> Record and store data using available technologies.	<b>11.A.2d</b> Use data to produce reasonable explanations.	<b>11.A.3d</b> Explain the existence of unexpected results in a data set.	<b>11.A.4d</b> Apply statistical methods to the data to reach and support conclusions.	<b>11.A.5d</b> Apply statistical methods to make predictions and to test the accuracy of results.
<b>11.A.1e</b> Arrange data into logical patterns and describe the patterns.	<b>11.A.2e</b> Report and display the results of individual and group investigations.	<b>11.A.3e</b> Use data manipulation tools and quantitative (e.g., mean, mode, simple equations) and representational methods (e.g., simulations, image processing) to analyze measurements.	<b>11.A.4e</b> Formulate alternative hypotheses to explain unexpected results.	<b>11.A.5e</b> Report, display and defend the results of investigations to audiences that may include professionals and technical experts.
<b>11.A.1f</b> Compare observations of individual and group results.		<b>11.A.3f</b> Interpret and represent results of analysis to produce findings.	<b>11.A.4f</b> Using available technology, report, display and defend to an audience conclusions drawn from investigations.	
		<b>11.A.3g</b> Report and display the process and results of a scientific investigation.		

**B. Know and apply the concepts, principles and processes of technological design.**

EARLY ELEMENTARY	LATE ELEMENTARY	MIDDLE/JUNIOR HIGH SCHOOL	EARLY HIGH SCHOOL	LATE HIGH SCHOOL
<b>11.B.1a</b> Given a simple design problem, formulate possible solutions.	<b>11.B.2a</b> Identify a design problem and propose possible solutions.	<b>11.B.3a</b> Identify an actual design problem and establish criteria for determining the success of a solution.	<b>11.B.4a</b> Identify a technological design problem inherent in a commonly used product.	<b>11.B.5a</b> Identify a design problem that has practical applications and propose possible solutions, considering such constraints as available tools, materials, time and costs.
<b>11.B.1b</b> Design a device that will be useful in solving the problem.	<b>11.B.2b</b> Develop a plan, design and procedure to address the problem identifying constraints (e.g., time, materials, technology).	<b>11.B.3b</b> Sketch, propose and compare design solutions to the problem considering available materials, tools, cost effectiveness and safety.	<b>11.B.4b</b> Propose and compare different solution designs to the design problem based upon given constraints including available tools, materials and time.	<b>11.B.5b</b> Select criteria for a successful design solution to the identified problem.
<b>11.B.1c</b> Build the device using the materials and tools provided.	<b>11.B.2c</b> Build a prototype of the design using available tools and materials.	<b>11.B.3c</b> Select the most appropriate design and build a prototype or simulation.	<b>11.B.4c</b> Develop working visualizations of the proposed solution designs (e.g., blueprints, schematics, flowcharts, cad-cam, animations).	<b>11.B.5c</b> Build and test different models or simulations of the design solution using suitable materials, tools and technology.
<b>11.B.1d</b> Test the device and record results using given instruments, techniques and measurement methods.	<b>11.B.2d</b> Test the prototype using suitable instruments, techniques and quantitative measurements to record data.	<b>11.B.3d</b> Test the prototype using available materials, instruments and technology and record the data.	<b>11.B.4d</b> Determine the criteria upon which the designs will be judged, identify advantages and disadvantages of the designs and select the most promising design.	<b>11.B.5d</b> Choose a model and refine its design based on the test results.
<b>11.B.1e</b> Report the design of the device, the test process and the results in solving a given problem.	<b>11.B.2e</b> Assess test results and the effectiveness of the design using given criteria and noting possible sources of error.	<b>11.B.3e</b> Evaluate the test results based on established criteria, note sources of error and recommend improvements.	<b>11.B.4e</b> Develop and test a prototype or simulation of the solution design using available materials, instruments and technology.	<b>11.B.5e</b> Apply established criteria to evaluate the suitability, acceptability, benefits, drawbacks and consequences for the tested design solution and recommend modifications and refinements.
	<b>11.B.2f</b> Report test design, test process and test results.	<b>11.B.3f</b> Using available technology, report the relative success of the design based on the test results and criteria.	<b>11.B.4f</b> Evaluate the test results based on established criteria, note sources of error and recommend improvements.	<b>11.B.5f</b> Using available technology, prepare and present findings of the tested design solution to an audience that may include professional and technical experts.
			<b>11.B.4g</b> Using available technology, report to an audience the relative success of the design based on the test results and criteria.	

APPENDIX C – NATIONAL SCIENCE TEACHER ASSOCIATION (NSTA)  
POSITION STATEMENT ON SCIENTIFIC INQUIRY

## **Declarations**

### **Regarding the use of scientific inquiry as a teaching approach, NSTA recommends that science teachers**

- Plan an inquiry-based science program for their students by developing both short- and long-term goals that incorporate appropriate content knowledge.
- Implement approaches to teaching science that cause students to question and explore and to use those experiences to raise and answer questions about the natural world. The learning cycle approach is one of many effective strategies for bringing explorations and questioning into the classroom.
- Guide and facilitate learning using inquiry by selecting teaching strategies that nurture and assess student's developing understandings and abilities.
- Design and manage learning environments that provide students with the time, space, and resources needed for learning science through inquiry.
- Receive adequate administrative support for the pursuit of science as inquiry in the classroom. Support can take the form of professional development on how to teach scientific inquiry, content, and the nature of science; the allocation of time to do scientific inquiry effectively; and the availability of necessary materials and equipment.
- Experience science as inquiry as a part of their teacher preparation program. Preparation should include learning how to develop questioning strategies, writing lesson plans that promote abilities and understanding of scientific inquiry, and analyzing instructional materials to determine whether they promote scientific inquiry.

### **Regarding students' abilities to *do* scientific inquiry, NSTA recommends that teachers help students**

- Learn how to identify and ask appropriate questions that can be answered through scientific investigations.
- Design and conduct investigations to collect the evidence needed to answer a variety of questions.
- Use appropriate equipment and tools to interpret and analyze data.
- Learn how to draw conclusions and think critically and logically to create explanations based on their evidence.
- Communicate and defend their results to their peers and others.

### **Regarding students' *understanding* about scientific inquiry, NSTA recommends that teachers help students understand**

- That science involves asking questions about the world and then developing scientific investigations to answer their questions.
- That there is no fixed sequence of steps that all scientific investigations follow. Different kinds of questions suggest different kinds of scientific investigations. •

That scientific inquiry is central to the learning of science and reflects how science is done.

- The importance of gathering empirical data using appropriate tools and instruments.
- That the evidence they collect can change their perceptions about the world and increase their scientific knowledge.
- The importance of being skeptical when they assess their own work and the work of others.
- That the scientific community, in the end, seeks explanations that are empirically based and logically consistent.

*Adopted by the  
NSTA Board of Directors  
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