Doing Science: The Process of Scientific Inquiry

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Please contact the NIH Office of Science Education with questions about this supplement at *supplements@science.education.nih.gov*.

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Foreword

This curriculum supplement, from *The NIH Curriculum Supplement Series*, brings cutting-edge medical science and basic research discoveries from the National Institutes of Health (NIH) into classrooms. As the largest medical research institution in the United States, NIH plays a vital role in the health of all Americans and seeks to foster interest in research, science, and medicine-related careers for future generations. The NIH Office of Science Education (OSE) is dedicated to promoting science education and scientific literacy.

We designed this curriculum supplement to complement existing life science curricula at both the state and local levels and to be consistent with the *National Science Education Standards*.[1] The supplement was developed and tested by a team composed of teachers from across the country; scientists; medical experts; other professionals with relevant subject-area expertise from institutes and medical schools across the country; representatives from the NIH National Institute of General Medical Sciences (NIGMS); and curriculum-design experts from Biological Sciences Curriculum Study (BSCS), AiGroup, and SAIC. The authors incorporated real scientific data and actual case studies into classroom activities. A two-year development process included geographically dispersed field tests by teachers and students.

The structure of this module enables teachers to effectively facilitate learning and stimulate student interest by applying scientific concepts to real-life scenarios. Design elements include a conceptual flow of lessons based on BSCS's 5E Instructional Model of Learning, multisubject integration that emphasizes cutting-edge science content, and built-in assessment tools. Activities promote active and collaborative learning and are inquiry-based, to help students develop problem-solving strategies and critical-thinking skills.

Each curriculum supplement comes with a complete set of materials for both teachers and students, including printed materials, extensive background and resource information, and a Web site with interactive activities. These supplements are distributed at no cost to teachers across the United States. All materials may be copied for classroom use, but may not be sold. We welcome feedback from our users. For a complete list of curriculum supplements, updates, and availability and ordering information, or to submit feedback, please visit our Web site at *http://science.education.nih.gov* or write to

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We appreciate the valuable contributions of the talented staff at BSCS, AiGroup, and SAIC. We are also grateful to the NIH scientists, advisers, and all other participating professionals for their work and dedication. Finally, we thank the teachers and students who participated in focus groups and field tests to ensure that these supplements are both engaging and effective. I hope you find our series a valuable addition to your classroom, and I wish you a productive school year.

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[1] In 1996, the National Academy of Sciences published the *National Science Education Standards*, which outlines what all citizens should understand about science by the time they graduate from high school. The *Standards* encourages teachers to select major science concepts that empower students to use information to solve problems rather than stressing memorization of unrelated information.

About the National Institutes of Health

Begun as the one-room Laboratory of Hygiene in 1887, the National Institutes of Health (NIH) today is one of the world's foremost medical research centers and the federal focal point for health research in the United States.

Mission and Goals

The NIH mission is science in pursuit of fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to extend healthy life and reduce the burdens of illness and disability. The goals of the agency are to

- foster fundamental creative discoveries, innovative research strategies, and their applications as a basis for advancing significantly the nation's capacity to protect and improve health;
- develop, maintain, and renew scientific resources — both human and physical — that will ensure the nation's ability to prevent disease;
- expand the knowledge base in medical and associated sciences in order to enhance the nation's economic well-being and ensure a continued high return on the public investment in research; and
- exemplify and promote the highest level of scientific integrity, public accountability, and social responsibility in the conduct of science.

NIH works toward meeting those goals by providing leadership, direction, and grant support to programs designed to improve the health of the nation through research in the

- causes, diagnosis, prevention, and cure of human diseases;
- processes of human growth and development;
- biological effects of environmental contaminants;
- understanding of mental, addictive, and physical disorders; and
- collection, dissemination, and exchange of information in medicine and health, including the development and support of medical libraries and the training of medical librarians and other health information specialists.

Organization

Composed of 27 separate institutes and centers, NIH is one of eight health agencies of the Public Health Service within the U.S. Department of Health and Human Services. NIH encompasses 75 buildings on more than 300 acres in Bethesda, Md., as well as facilities at several other sites in the United States. The NIH budget has grown from about $300 in 1887 to more than $28 billion in 2005.

Research Programs

One of NIH's principal concerns is to invest wisely the tax dollars entrusted to it for the support and conduct of this research. Approximately 82 percent of the investment is made through grants and contracts supporting research and training in more than 2,000 research institutions throughout the United States and abroad. In fact, NIH grantees are located in every state in the country. These grants and contracts make up the NIH Extramural Research Program.

Approximately 10 percent of the budget goes to NIH's Intramural Research Programs, the more than 2,000 projects conducted mainly in its own laboratories. These projects are central to the NIH scientific effort. First-rate intramural scientists collaborate with one another regardless of institute affiliation or scientific discipline and have the intellectual freedom to pursue their research leads in NIH's own laboratories. These explorations range from basic biology to behavioral research, to studies on treatment of major diseases.

Grant-Making Process

The grant-making process begins with an idea that an individual scientist describes in a written application for a research grant. The project might be small, or it might involve millions of dollars. The project might become useful immediately as a diagnostic test or new treatment, or it might involve studies of basic biological processes whose clinical value may not be apparent for many years.

Each research grant application undergoes peer review. A panel of scientific experts, primarily from outside the government, who are active and productive researchers in the biomedical sciences, first evaluates the scientific merit of the application. Then, a national advisory council or board, composed of eminent scientists as well as members of the public who are interested in health issues or the biomedical sciences, determines the project's overall merit and priority in advancing the research agenda of the particular NIH funding institutes.

About 38,500 research and training applications are reviewed annually through the NIH peer-review system. At any given time, NIH supports 35,000 grants in universities, medical schools, and other research and research training institutions, both nationally and internationally.

NIH Nobelists

The roster of people who have conducted NIH research or who have received NIH support over the years includes some of the world's most illustrious scientists and physicians. Among them are 115 winners of Nobel Prizes for achievements as diverse as deciphering the genetic code and identifying the causes of hepatitis. You can learn more about Nobelists who have received NIH support at *http://www.nih.gov/about/almanac/nobel/index.htm.*

Impact on the Nation's Health

Through its research, NIH has played a major role in making possible many achievements over the past few decades, including these:

- Mortality from heart disease, the number one killer in the United States, dropped by 36 percent between 1977 and 1999.
- Improved treatments and detection methods increased the relative five-year survival rate for people with cancer to 60 percent.
- With effective medications and psychotherapy, the 19 million Americans who suffer from depression can now look forward to a better, more productive future.
- Vaccines are now available that protect against infectious diseases that once killed and disabled millions of children and adults.
- In 1990, NIH researchers performed the first trial of gene therapy in humans. Scientists are increasingly able to locate, identify, and describe the functions of many of the genes in the human genome. The ultimate goal is to develop screening tools and gene therapies for the general population for cancer and many other diseases.

Science Education

Science education by NIH and its institutes contributes to ensuring the continued supply of well-trained basic research and clinical investigators, as well as the myriad professionals in the many allied disciplines who support the research enterprise. These efforts also help educate people about scientific results so that they can make informed decisions about their own—and the public's—health.

This curriculum supplement is one such science education effort, a collaboration among three partners: the NIH National Institute of General Medical Sciences, the NIH Office of Science Education, and Biological Sciences Curriculum Study.

For more about NIH, visit *http://www.nih.gov.*

About the National Institute of General Medical Sciences

Many scientists across the country are united by one chief desire: to improve our understanding of how life works. Whether they gaze at or grind up, create or calculate, model or manipulate, if their work sheds light on living systems, it may well receive financial support from the National Institute of General Medical Sciences (NIGMS), which funds the research of more than 3,000 scientists at universities, medical schools, hospitals, and other research institutions.

NIGMS is part of the National Institutes of Health (NIH), an agency of the U.S. government that is one of the world's leading supporters of biomedical research. As the "General" in its name implies, NIGMS has broad interests. It funds basic research in cell biology, structural biology, genetics, chemistry, pharmacology, and many other fields. This work teaches us about the molecules, cells, and tissues that form all living creatures. It helps us understand—and possibly find new ways to treat—diseases caused by malfunctions in these biological building blocks. NIGMS also supports training programs that provide the most critical element of good research: well-prepared scientists.

Science is a never-ending story. The solution of one mystery is the seed of many others. Research in one area may also provide answers to questions in other, seemingly unrelated, areas. The anticancer drug cisplatin unexpectedly grew out of studies on the effect of electrical fields on bacteria. Freeze-drying was developed originally by researchers as a way to concentrate and preserve biological samples. And a laboratory technique called the polymerase chain reaction became the basis of "DNA fingerprinting" techniques that have revolutionized criminal forensics.

Similarly, it is impossible to predict the eventual impact and applications of the basic biomedical research that NIGMS supports. But one thing is certain: these studies will continue to supply missing pieces in our understanding of human health and will lay the foundation for advances in disease prevention, diagnosis, and treatment.

For more information, visit the NIGMS Web site: *www.nigms.nih.gov.*

To order print copies of free NIGMS science education publications, visit *http://www.nigms.nih.gov/Publications/ScienceEducation.htm.*

Introduction to Doing Science: *The Process of Scientific Inquiry*

We are living in a time when science and technology play an increasingly important role in our everyday lives. By almost any measure, the pace of change is staggering. Recent inventions and new technologies are having profound effects on our economic, political, and social systems. The past 30 years have seen the

- advent of recombinant DNA technology,
- development of in vitro fertilization techniques,
- cloning of mammals,
- creation of the Internet,
- birth of nanotechnology, and
- mass introduction of fax machines, cell phones, and personal computers.

These advances have helped improve the lives of many, but they also raise ethical, legal, and social questions. If society is to reap the benefits of science while minimizing potential negative effects, then it is important for the public to have the ability to make informed, objective decisions regarding the applications of science and technology. This argues for educating the public about the scientific process and how to distinguish science from pseudoscience.

What Are the Objectives of the Module?

Doing Science: The Process of Scientific Inquiry has four objectives. The first is to help students understand the basic aspects of scientific inquiry. Science proceeds by a continuous, incremental process that involves generating hypotheses, collecting evidence, testing hypotheses, and reaching evidence-based conclusions. Rather than involving one particular method, scientific inquiry is flexible. Different types of questions require different types of investigations. Moreover, there is more than one way to answer a question. Although students may associate science with experimentation, science also uses observations, surveys, and other nonexperimental approaches.

The second objective is to provide students with an opportunity to practice and refine their critical-thinking skills. Such abilities are important, not just for scientific pursuits, but for making decisions in everyday life. Our fast-changing world requires today's youth to be life-long learners. They must be able to evaluate information from a variety of sources and assess its usefulness. They need to discriminate between objective science and pseudoscience. Students must be able to establish causal relationships and distinguish them from mere associations.

The third objective is to convey to students the purpose of scientific research. Ongoing research affects how we understand the world around us and provides a foundation for improving our choices about personal health and the health of our community. In this module, students participate in a virtual investigation that gives them experience with the major aspects of scientific inquiry. The lessons encourage students to think about the relationships among knowledge, choice, behavior, and human health in this way:

Knowledge (what is known and not known) + Choice = Power

Power + Behavior = Enhanced Human Health

The final objective of this module is to encourage students to think in terms of these relationships now and as they grow older.

Why Teach the Module?

Middle school life science classes offer an ideal setting for integrating many areas of student interest. In this module, students participate in activities that integrate inquiry science, human health, and mathematics, and interweave science, technology, and society. The real-life context of the module's classroom lessons is engaging, and the knowledge gained can be applied immediately to students' lives.

What's in It for the Teacher?

Doing Science: The Process of Scientific Inquiry meets many of the criteria by which teachers and their programs are assessed:

- The module is **standards based** and meets science content, teaching, and assessment standards as expressed in the *National Science Education Standards*. It pays particular attention to the standards that describe what students should know and be able to do with respect to **scientific inquiry**. Where appropriate, we use a standards icon to make connections to the standards explicit.
- It is an **integrated** module, drawing most heavily from the subjects of science, social science, mathematics, and health.
- The module has a Web-based **technology component**, which includes interactive graphics and video clips.
- The module includes built-in **assessment** tools, which are noted in each of the lessons with an assessment icon.

In addition, the module provides a means for *professional development*. Teachers can engage in new and different teaching practices such as those described in this module without completely overhauling their entire program.

In *Designing Professional Development for Teachers of Science and Mathematics*, Loucks-Horsley et al. write that supplements such as this one "offer a window through which teachers get a glimpse of what new teaching strategies look like in action."[7] By experiencing a short-term unit, teachers can "change how they think about teaching and embrace new approaches that stimulate students to problem-solve, reason, investigate, and construct their own meaning for the content." The use of this kind of supplemental unit can encourage reflection and discussion and stimulate teachers to improve their practices by focusing on student learning through inquiry.

The following table correlates topics often included in science curricula with the major concepts presented in this module. This information is presented to help you make decisions about incorporating this material into your curriculum.

Correlation of *Doing Science: The Process of Scientific Inquiry* to Middle School Science Topics

Topics	Lesson 1	Lesson 2	Lesson 3	Lesson 4
Populations and ecosystems	✓			✓
The nature of science	✓	✓	✓	✓
Natural hazards			✓	✓
Human health and medicine			✓	✓
Relationship of science, technology, and society	✓	✓	✓	✓

Implementing the Module

The four lessons of this module are designed to be taught in sequence over six to eight days (as a supplement to the standard curriculum) or as individual lessons that support and enhance your treatment of specific concepts in middle school science. This section offers general suggestions about using these materials in the classroom. You will find specific suggestions in the procedures provided for each lesson.

What Are the Goals of the Module?

Doing Science: The Process of Scientific Inquiry helps students achieve four major goals associated with scientific literacy:

- to understand a set of basic elements related to the process of scientific inquiry,
- to experience the process of scientific inquiry and develop an enhanced understanding of the nature and methods of science,
- to hone critical-thinking skills, and
- to recognize the role of science in society and the relationship between basic science and human health.

What Are the Science Concepts and How Are They Connected?

The lessons are organized into a conceptual framework that allows students to move from what they already know about scientific inquiry, or think they know, to gaining a more complete and accurate perspective on the nature of scientific inquiry. Students model the process of scientific inquiry using a paper-cube activity (Lesson 1, *Inquiring Minds*). They then explore questions and what distinguishes those questions that can be tested by a scientific investigation from those that cannot (Lesson 2, *Working with Questions*). Students then participate in a computer-based scientific investigation as members of a fictitious community health department. In this investigation, students gain experience with the major aspects of scientific inquiry and critical thinking (Lesson 3, *Conducting a Scientific Investigation*). Students then reflect on what they have learned about the process of scientific inquiry. Continuing in their roles as members of the community health department, students analyze data and prepare investigative reports. They also evaluate reports prepared by others (Lesson 4, *Pulling It All Together*). The table on page 4 illustrates the scientific content and conceptual flow of the four lessons.

How Does the Module Correlate with the *National Science Education Standards*?

NSES

Doing Science: The Process of Scientific Inquiry supports teachers in their efforts to reform science education in the spirit of the National Academy of Sciences' 1996 *National Science Education Standards* (NSES). The content is explicitly standards based. Each time a standard is addressed in a lesson, an icon appears in the margin and the applicable standard is identified. The table on page 5 lists the specific content standards that this module addresses.

Teaching Standards

The suggested teaching strategies in all of the lessons support you as you work to meet the teaching standards outlined in the *National Science Education Standards*. This module helps teachers of science plan an inquiry-based science program by providing short-term objectives for students. It also includes planning tools such as the Science Content and Conceptual Flow of the Lessons table and the Suggested Timeline for teaching the module. You can use this module to update your curriculum in response to students' interest. The focus on active, collaborative, and inquiry-

Science Content and Conceptual Flow of the Lessons

Lesson and Learning Focus*	Topics Covered and Major Concepts
1: Inquiring Minds ***Engage***: Students become engaged in the process of scientific inquiry.	***Scientists learn about the natural world through scientific inquiry.*** • Scientists ask questions that can be answered through investigations. • Scientists design and carry out investigations. • Scientists think logically to make relationships between evidence and explanations. • Scientists communicate procedures and explanations.
2: Working with Questions ***Explore:*** Students consider what makes questions scientifically testable. Students gain a common set of experiences upon which to begin building their understanding.	***Scientists ask questions that can be answered through investigations.*** • Testable questions are not answered by personal opinions or belief in the supernatural. • Testable questions are answered by collecting evidence and developing explanations based on that evidence.
3: Conducting a Scientific Investigation ***Explain/Elaborate:*** Students conduct an investigation in the context of a community health department. They propose possible sources of the health problem and describe how they might confirm or refute these possibilities.	***Scientific explanations emphasize evidence.*** • Scientists think critically about the types of evidence that should be collected. ***Scientists analyze the results of their investigations to produce scientifically acceptable explanations.***
4: Pulling It All Together ***Evaluate:*** Students deepen their understanding of scientific inquiry by performing their own investigation and evaluating one performed by another student.	***Scientific inquiry is a process of discovery.*** • It begins with a testable question. • Scientific investigations involve collecting evidence. • Explanations are evidence based. • Scientists communicate their results to their peers.

*See *How Does the 5E Instructional Model Promote Active, Collaborative, Inquiry-Based Learning?* on page 6.

based learning in the lessons helps support the development of student understanding and nurtures a community of science learners.

The structure of the lessons enables you to guide and facilitate learning. All the activities encourage and support student inquiry, promote discourse among students, and challenge students to accept and share responsibility for their learning. The use of the 5E Instructional Model, combined with active, collaborative learning, allows you to respond effectively to students with diverse backgrounds and learning styles. The module is fully annotated, with suggestions for how you can encourage and model the skills of scientific inquiry and foster curiosity, openness to new ideas and data, and skepticism.

Assessment Standards

You can engage in ongoing assessment of your instruction and student learning using the assessment components. The assessment tasks are authentic; they are similar to tasks that students will engage in outside the classroom or to practices in which scientists participate.

Content Standards: Grades 5–8

Standard A: Science as Inquiry **As a result of their activities in grades 5–8, all students should develop**	**Correlation to *Doing Science: The Process of Scientific Inquiry***
Abilities necessary to do scientific inquiry	
• Identify questions that can be answered through scientific investigations.	All lessons
• Use appropriate tools and techniques to gather, analyze, and interpret data.	Lessons 1, 3, 4
• Develop descriptions, explanations, predictions, and models using evidence.	Lessons 1, 3, 4
• Think critically and logically to make the relationships between evidence and explanations.	Lessons 1, 3, 4
• Recognize and analyze alternative explanations and predictions.	Lessons 1, 3, 4
• Communicate scientific procedures and explanations.	Lessons 1, 3, 4
• Use mathematics in all aspects of scientific inquiry.	Lessons 3, 4
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 some involve making models.	All lessons
• Mathematics is important in all aspects of scientific inquiry.	Lessons 3, 4
Standard C: Life Science **As a result of their activities in grades 5–8, all students should develop an understanding of**	
Structure and function in living systems	
• Some diseases are the result of intrinsic failures of the system. Others are the result of damage by infection by other organisms.	Lessons 3, 4
Populations and ecosystems	
• Food webs identify the relationships among producers, consumers, and decomposers in an ecosystem.	Lesson 1
Standard E: Science and Technology **As a result of their activities in grades 5–8, all students should develop**	
Understandings about science and technology	
• Science and technology are reciprocal. Science helps drive technology. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable.	Lessons 2, 3, 4
Standard F: Science in Personal and Social Perspectives **As a result of their activities in grades 5–8, all students should develop an understanding of**	
Personal health	
• The potential for accidents and the existence of hazards imposes the need for injury prevention. Safe living involves the development and use of safety precautions and the recognition of risk in personal decisions.	Lessons 3, 4

Risks and benefits	
• Risk analysis considers the type of hazard and estimates the number of people who might be exposed and the number likely to suffer consequences. The results are used to determine the options for reducing or eliminating risks.	Lessons 3, 4
• Important personal and social decisions are made based on perceptions of benefits and risks.	Lesson 3
Science and technology in society	
• Technology influences society through its products and processes. Technology influences the quality of life and the ways people act and interact.	Lesson 2
Standard G: History and Nature of Science **As a result of their activities in grades 5–8, all students should develop an understanding of**	
Science as a human endeavor	
• Science requires different abilities, depending on such factors as the field of study and type of inquiry. Science is very much a human endeavor, and the work of science relies on basic human qualities, such as reasoning, insight, energy, skills, and creativity.	All lessons
Nature of science	
• Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.	All lessons

Annotations will guide you to these assessment opportunities and provide answers to questions that will help you analyze student feedback.

How Does the 5E Instructional Model Promote Active, Collaborative, Inquiry-Based Learning?

Because learning does not occur by way of passive absorption, the lessons in this module promote active learning. Students are involved in more than listening and reading. They are developing skills, analyzing and evaluating evidence, experiencing and discussing, and talking to their peers about their own understanding. Students work collaboratively with others to solve problems and plan investigations. Many students find that they learn better when they work with others in a collaborative environment than when they work alone in a competitive environment. When active, collaborative learning is directed toward scientific inquiry, students succeed in making their own discoveries. They ask questions, observe, analyze, explain, draw conclusions, and ask new questions. These inquiry-based experiences include both those that involve students in direct experimentation and those in which students develop explanations through critical and logical thinking.

The viewpoint that students are active thinkers who construct their own understanding from interactions with phenomena, the environment, and other individuals is based on the theory of constructivism. A constructivist view of learning recognizes that students need time to

- express their current thinking;
- interact with objects, organisms, substances, and equipment to develop a range of experiences on which to base their thinking;
- reflect on their thinking by writing and expressing themselves and comparing what they think with what others think; and
- make connections between their learning experiences and the real world.

This module provides a built-in structure for creating a constructivist classroom: the 5E Instructional Model. The 5E model sequences learning experiences so that students have the opportunity to construct their understanding of a concept over time. The model leads students through five phases of learning that are easily described using words that begin with the letter E: Engage, Explore, Explain, Elaborate, and Evaluate. The following paragraphs illustrate how the five Es are implemented across the lessons in this module.

Engage

Students come to learning situations with prior knowledge. This knowledge may or may not be congruent with the concepts presented in this module. The Engage lesson provides the opportunity for teachers to find out what students already know, or think they know, about the topic and concepts to be covered. The Engage lesson in this module, Lesson 1, *Inquiring Minds*, is designed to

- pique students' curiosity and generate interest,
- determine students' current understanding about scientific inquiry,
- invite students to raise their own questions about the process of scientific inquiry,
- encourage students to compare their ideas with those of others, and
- enable teachers to assess what students do or do not understand about the stated outcomes of the lesson.

Explore

In the Explore phase of the module, Lesson 2, *Working with Questions*, students investigate the nature of scientifically testable questions. Students engage in short readings and generate their own set of testable questions. This lesson provides a common set of experiences within which students can begin to construct their understanding. Students

- interact with materials and ideas through classroom and small–group discussions;
- consider different ways to solve a problem or frame a question;
- acquire a common set of experiences so that they can compare results and ideas with their classmates;
- observe, describe, record, compare, and share their ideas and experiences; and
- express their developing understanding of testable questions and scientific inquiry.

Explain

The Explain lesson (Lesson 3, *Conducting a Scientific Investigation*) provides opportunities for students to connect their previous experiences with current learning and to make conceptual sense of the main ideas of the module. This stage also allows for the introduction of formal language, scientific terms, and content information that might make students' previous experiences easier to describe. The Explain lesson encourages students to

- explain concepts and ideas (in their own words) about a potential health problem;
- listen to and compare the explanations of others with their own;
- become involved in student-to-student discourse in which they explain their thinking to others and debate their ideas;
- revise their ideas;
- record their ideas and current understanding;
- use labels, terminology, and formal language; and
- compare their current thinking with what they previously thought.

Elaborate

In Elaborate lessons, students apply or extend previously introduced concepts and experiences to new situations. In the Elaborate lesson in this module, Lesson 3, *Conducting a Scientific Investigation*, students

- make conceptual connections between new and former experiences, connecting aspects of their health department investigation with their concepts of scientific inquiry;
- connect ideas, solve problems, and apply their understanding to a new situation;
- use scientific terms and descriptions;
- draw reasonable conclusions from evidence and data;
- deepen their understanding of concepts and processes; and
- communicate their understanding to others.