

### Practice 3 Planning and Carrying Out Investigations

*Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students’ own questions. (NRC Framework, 2012, p. 61)*

Scientific investigations may be undertaken to describe a phenomenon, or to test a theory or model for how the world works. The purpose of engineering investigations might be to find out how to fix or improve the functioning of a technological system or to compare different solutions to see which best solves a problem. Whether students are doing science or engineering, it is always important for them to state the goal of an investigation, predict outcomes, and plan a course of action that will provide the best evidence to support their conclusions. Students should design investigations that generate data to provide evidence to support claims they make about phenomena. Data aren’t evidence until used in the process of supporting a claim. Students should use reasoning and scientific ideas, principles, and theories to show why data can be considered evidence.

Over time, students are expected to become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables should be treated as results or outputs, which should be treated as inputs and intentionally varied from trial to trial, and which should be controlled, or kept the same across trials. In the case of field observations, planning involves deciding how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator. Planning and carrying out investigations may include elements of all of the other practices.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
<p>Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions.</p> <ul style="list-style-type: none"> <li>• With guidance, plan and conduct an investigation in collaboration with peers (for K).</li> <li>• Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence to answer a question.</li> <li>• Evaluate different ways of observing and/or measuring a phenomenon to determine which way can answer a question.</li> <li>• Make observations (firsthand or from media) and/or measurements to collect data that can be used to make comparisons.</li> <li>• Make observations (firsthand or from media) and/or measurements of a proposed object or tool or solution to determine if it</li> </ul>	<p>Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on K–2 experiences and progresses to include investigations that <u>control variables</u> and provide evidence to support explanations or design solutions.</p> <ul style="list-style-type: none"> <li>• Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.</li> <li>• Evaluate appropriate methods and/or tools for collecting data.</li> <li>• Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution.</li> <li>• Make predictions about what would happen if a variable changes.</li> <li>• Test two different models of the same proposed object, tool, or process to</li> </ul>	<p>Planning and carrying out investigations in 6-8 builds on K-5 experiences and progresses to include investigations that use <u>multiple variables</u> and provide evidence to support explanations or solutions.</p> <ul style="list-style-type: none"> <li>• Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.</li> <li>• Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.</li> <li>• Evaluate the accuracy of various methods for collecting data.</li> <li>• Collect data to produce data to serve as the basis for evidence to answer scientific questions or test</li> </ul>	<p>Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.</p> <ul style="list-style-type: none"> <li>• Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation’s design to ensure variables are controlled.</li> <li>• Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.</li> <li>• Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.</li> <li>• Select appropriate tools to collect, record, analyze, and evaluate data.</li> </ul>

<p>solves a problem or meets a goal.</p> <ul style="list-style-type: none"> <li>• Make predictions based on prior experiences.</li> </ul>	<p>determine which better meets criteria for success.</p>	<p>design solutions under a range of conditions.</p> <ul style="list-style-type: none"> <li>• Collect data about the performance of a proposed object, tool, process or system under a range of conditions.</li> </ul>	<ul style="list-style-type: none"> <li>• Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated.</li> <li>• Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.</li> </ul>
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More sophisticated types of models should increasingly be used across the grades, both in instruction and curriculum materials, as students progress through their science education. The quality of a student-developed model will be highly dependent on prior knowledge and skill and also on the student’s understanding of the system being modeled, so students should be expected to refine their models as their understanding develops. Curricula will need to stress the role of models explicitly and provide students with modeling tools (e.g., Model-It, agent-based modeling such as NetLogo, spreadsheet models), so that students come to value this core practice and develop a level of facility in constructing and applying appropriate models.

### **Practice 3** **Planning and Carrying Out Investigations**

Scientists and engineers investigate and observe the world with essentially two goals: (1) to systematically describe the world and (2) to develop and test theories and explanations of how the world works. In the first, careful observation and description often lead to identification of features that need to be explained or questions that need to be explored.

The second goal requires investigations to test explanatory models of the world and their predictions and whether the inferences suggested by these models are supported by data. Planning and designing such investigations require the ability to design experimental or observational inquiries that are appropriate to answering the question being asked or testing a hypothesis that has been formed. This process begins by identifying the relevant variables and considering how they might be observed, measured, and controlled (constrained by the experimental design to take particular values).

Planning for controls is an important part of the design of an investigation. In laboratory experiments, it is critical to decide which variables are to be treated as results or outputs and thus left to vary at will and which are to be treated as input conditions and hence controlled. In many cases, particularly in the case of field observations, such planning involves deciding what can be controlled and how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator.

Decisions must also be made about what measurements should be taken, the level of accuracy required, and the kinds of instrumentation best suited to making such measurements. As in other forms of inquiry, the key issue is one of precision—the goal is to measure the variable as accurately as possible and reduce sources of error. The investigator must therefore decide what constitutes

a sufficient level of precision and what techniques can be used to reduce both random and systematic error.

## GOALS

By grade 12, students should be able to

- Formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (that is, a possible explanation that predicts a particular and stable outcome) based on a model or theory.
- Decide what data are to be gathered, what tools are needed to do the gathering, and how measurements will be recorded.
- Decide how much data are needed to produce reliable measurements and consider any limitations on the precision of the data.
- Plan experimental or field-research procedures, identifying relevant independent and dependent variables and, when appropriate, the need for controls.
- Consider possible confounding variables or effects and ensure that the investigation’s design has controlled for them.

## PROGRESSION

Students need opportunities to design investigations so that they can learn the importance of such decisions as what to measure, what to keep constant, and how to select or construct data collection instruments that are appropriate to the needs of an inquiry. They also need experiences that help them recognize that the laboratory is not the sole domain for legitimate scientific inquiry and that, for many scientists (e.g., earth scientists, ethologists, ecologists), the “laboratory” is the natural world where experiments are conducted and data are collected in the field.

In the elementary years, students’ experiences should be structured to help them learn to define the features to be investigated, such as patterns that suggest causal relationships (e.g., What features of a ramp affect the speed of a given ball as it leaves the ramp?). The plan of the investigation, what trials to make and how to record information about them, then needs to be refined iteratively as students recognize from their experiences the limitations of their original plan. These investigations can be enriched and extended by linking them to engineering design projects—for example, how can students apply what they have learned about ramps to design a track that makes a ball travel a given distance, go around a loop, or stop on an uphill slope. From the earliest grades, students should have

opportunities to carry out careful and systematic investigations, with appropriately supported prior experiences that develop their ability to observe and measure and to record data using appropriate tools and instruments.

Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students' own



questions. As they become more sophisticated, students also should have opportunities not only to identify questions to be researched but also to decide what data are to be gathered, what variables should be controlled, what tools or instruments are needed to gather and record data in an appropriate format, and eventually to consider how to incorporate measurement error in analyzing data.

Older students should be asked to develop a hypothesis that predicts a particular and stable outcome and to explain their reasoning and justify their choice. By high school, any hypothesis should be based on a well-developed model or theory. In addition, students should be able to recognize that it is not always possible to control variables and that other methods can be used in such cases—for example, looking for correlations (with the understanding that correlations do not necessarily imply causality).

#### **Practice 4 Analyzing and Interpreting Data**

Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence.