

### 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).