Inquiry boards are excellent tools for highlighting the role of variables in an experiment.

By Helen Buttemer

> *Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with the processes of inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques, thinking critically and logically about the relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments.*
>
> (NRC 1996, p. 105)

Whew! This is a tall order! Where does a teacher begin?

In our workshops on investigative sciences for preservice and inservice K–8 teachers at the University of Washington, we begin with an essential part of any scientific investigation: variables.

Helping students to identify variables can be the key to other aspects of an investigation, such as the use of tables or graphs. In this article, we describe a tool we have successfully used to highlight the role of variables in an experiment: inquiry boards. Adapted from *Making Sense of Primary Science Investigations* (Goldworthy and Feasely 1997), inquiry boards consist of eight *boards* (cardboard works well) that sequentially lead students through the experimental process: Brainstorm Variables; Choose Variables; Ask a Question; Predict an Outcome; Set up the Experiment; Table of Results; Look for Patterns and Graph of Results; and Answer the Question.

Blank spaces on the boards indicate places to attach self-stick notes on which the teacher or student can list the variables. We use different colored notes to distinguish between variables. The notes can easily be moved from poster to poster—demonstrating the logic of the sequence—and the posters themselves can be reused numerous times.

This process of conducting an investigation—from framing the testable question to answering the question with evidence—requires a student to understand the anatomy of an investigation and the relationship between variables (see Figure 1). We have found no better tool for introducing the logic of this relationship than inquiry boards.

The inquiry board–supported investigation described here uses "baggie gardens" to explore questions about seed growth and was used with elementary teachers as a simple introduction to the experimental process for students. Inquiry boards work well for students of any age; however, teachers working with younger students (grade 3 or younger) may want to simplify the vocabulary accordingly. The example below assigns names to the variables in an experiment but the terms can easily be described without compromising the experiment.

Brainstorm

The teacher begins by describing the problem to be studied. In this example, preparing students for the baggie garden exploration, the teacher might ask, "*What kind of things affect seed germination?*" and then invent a related story based on the age and interests of the students: "The farmers in the Kingdom of Pod are having a terrible time getting their seeds to grow. The people are hungry, the King is worried, and the Chief of Agriculture has asked for our help. Let's do some experiments to help them understand what affects how seeds grow."

Figure 1.

Anatomy of an investigation.

Testable Question + Variables + Replicates = Experimental Setup

Testable Question:

A question that asks about how the manipulated variable affects the responding variable.

Variables:

Manipulated (or independent) Variable. Something that is deliberately changed in the test setup so that you can observe the effect.

Controlled Variable. The factors in the test setup that are kept the same as in the control setup, so the only thing being tested is the effect of the manipulated variable.

Responding (or dependent) Variable. What will be measured or observed, which may or may not change in response to the manipulated variable.

Replicates:

# of Trials or Subjects. The number of times the experiment is repeated or the number of individuals tested in one experiment.

Experimental Setup:

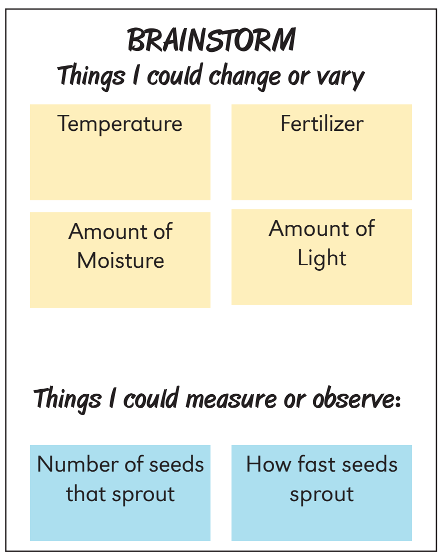
Test Setup. The setup in which the manipulated variable is changed.

Control (or comparison) Setup. The setup in which the manipulated variable has not been changed. This serves as a comparison to the test setup.

Data Table. An organized table for recording results.

Figure 2.

Brainstorm Variables.



Then, the teacher and students create baggie gardens to test their ideas. (Baggie gardens can be easily constructed by placing a folded, moistened paper towel inside a sealable plastic bag. Staple the bag above the paper towel, about 2.5 cm from the bottom of the bag, and place the seeds—we have used lentil seeds—on top of the line of staples. Finally, close the baggie, and await the seeds' germination. Lentils, for example, will germinate within 48 hours at room temperature.)

After the baggie gardens are made, students brainstorm ways in which seeds could be studied by changing something in the baggie garden. Students typically suggest changing the amount of water, temperature, amount of light, color of the light, kind of seeds, number of seeds, spacing of the seeds, fertilizer, pollutants, etc. The teacher writes each suggestion on a separate self-stick note and places it under "Things I Could Change or Vary" on the Brainstorm inquiry board (Figure 2, p. 35). Teachers can jumpstart the brainstorming process by asking students about what affects how a seed grows and by showing various materials (e.g., samples of fertilizer or common pollutants such as soap) to spur students' ideas.

Next the teacher asks, "*What could we measure or observe about how the seeds grow?*" Students may suggest measuring the number of seeds that sprout, the time for seeds to sprout, the size of the sprouts, the color of the leaves, and so on. Again, each suggestion is written on a separate self-stick note and placed under "Things I Could Measure or Observe." *Note:* It works well to use one color of self-stick notes for "Things I could Change or Vary" (e.g., yellow) and a different color for "Things I Could Measure" (e.g., blue). This will help students to see the logical flow of these variables throughout the experiment.

Choose Variables

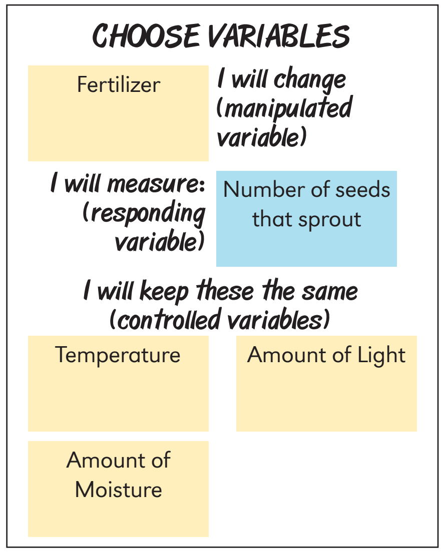
At this point, countless potential experiments exist. Students choose one variable to investigate, such as the effect of fertilizers on seeds. Then, the teacher moves the yellow self-stick note with "fertilizer" written on it to the Choose Variables inquiry board (Figure 3) and places it next to or under the phrase "I Will Change (fertilizer)." This is the *manipulated* variable in the experiment (the manipulated variable is also known as the independent variable).

Students then decide what to measure in order to investigate how fertilizer affects seeds (e.g., number of seeds that sprout). The teacher then moves the appropriate blue self-stick note to the "I Will Measure (number of seeds that sprout)" area of the inquiry board, labeled the *responding* variable (the responding variable is also known as the dependent variable).

Next, the teacher asks the students how they can be sure that any effect on the seeds is due only to the addition of fertilizer and not to other variables. Students easily recognize that all the other things they initially brainstormed changing (amount of water, amount of light, kind of seeds, and so on) must not be changed in order for the experiment to be fair.

Figure 3.

Choose Variables.



At this point all the remaining yellow self-stick notes are moved from "Things I Could Change or Vary" to "I Will Keep These the Same" or *controlled* variables. This is a visual demonstration of how only one thing is changed in an experiment, everything else is held constant.

We have chosen to use the term *manipulated variable* instead of the traditionally used *independent variable* because this is a more intuitive term. After all, the manipulated variable is the one thing that is *manipulated* or changed in an experiment. Everything else is kept the same or controlled (i.e., *controlled variables*). Similarly, the dependent variable is called the *responding variable* because this is what may *respond* to the change in the experiment. Hence, the responding variable is what will be measured and recorded to assess the effect of the manipulated variable on the experiment. Teachers working with younger students may simply refer to these variables as "what was changed," "what was measured," and "what was kept the same."

Ask a Question

Using this inquiry board (Figure 4), students frame the experimental question. To do this, students place the yellow self-stick note with the manipulated variable (e.g., fertilizer) under "When I change ______" and the blue one with the responding variable (e.g., number of seeds that sprout) under "What happens to ______?"

Formulating a question is often easier for a beginning science student than formulating a hypothesis—and an equally valid way of conducting a scientific investigation. A scientific question measures the effect of one variable (the manipulated variable) on a measurable outcome (the responding variable).

Predict an Outcome

Making predictions is an important part of any experiment, but unless students have prior knowledge, predicting can turn into guessing. This inquiry board (Figure 5) helps students frame their predictions. One way to encourage thinking is to have students construct predictions in this fashion: "When I change ___________ (the manipulated variable, e.g., when I add fertilizer to seeds), I predict that ___________ (e.g., more seeds will sprout) will happen to what I measure (the responding variable, e.g., how many seeds sprout) because ___________ (e.g., the bottle of plant fertilizer claims that it helps plants grow better so maybe it also helps them sprout faster)."

Students sometimes have difficulty predicting because they are used to being told what the expected outcome should be or because they are afraid of being "wrong." Thinking about what makes sense without having to be "right" is the heart of critical thinking and central to investigative science.

In our classes, students are always asked to justify their thinking: *Tell me why you think this will happen?* Logical thinking in which a student connects a prediction to other knowledge or observations is more important than being "right." Teachers can model this process for students by thinking out loud: "I know this about _______ and so it makes sense to me that this would happen (_______) when we change _______." For example, "*Plants need something called nutrients to grow. Sometimes we use fertilizers to supply nutrients for healthy plants so I wonder if fertilizers could also help seeds to grow.*" We accept all predictions, provided students can provide some logical explanation.

Set Up Experiment

The Set Up Experiment inquiry board (Figure 6) helps students visualize the experiment and understand the need for a control or comparison. On this board, students report how they will change the manipulated variable and what they will compare their test to (the *control setup*). In our experiment investigating the effect of fertilizer on seed germination, students make decisions about how the baggie with fertilizer will be set up, including decisions about which product to test, how much product to use, what kind and how many seeds to use, and where to place the baggies.

Students may suggest testing different kinds of fertilizers to see which is a better fertilizer. Reminding them that the original experimental question, "When I add fertilizer to seeds what happens to the number of seeds that sprout?" does not specify how much fertilizer or compare different brands of fertilizer. It's perfectly okay to test different products or different concentrations of fertilizer, but each of these constitutes yet another change in the manipulated variable. Because we want to change only one thing in the test baggie, each new change requires a new baggie garden and is technically a new test.

For simplicity, a teacher may limit students to one test (i.e., one kind of fertilizer).

Figure 4.

Ask a Question.

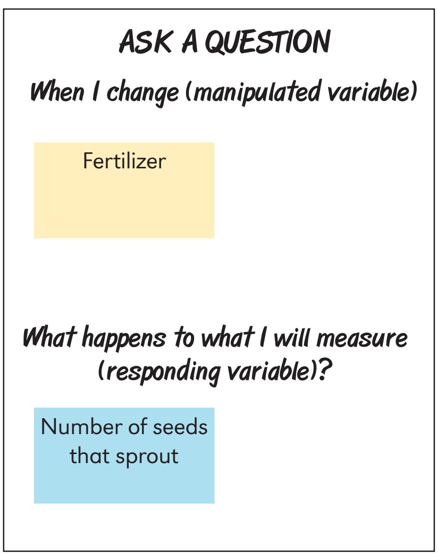


Figure 5.

Predict an Outcome.

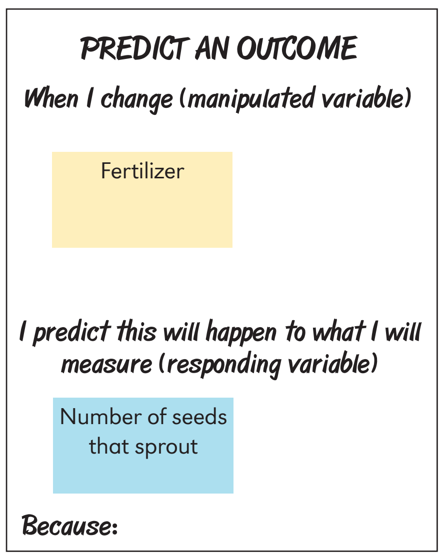


Figure 6.

Set Up Experiment.

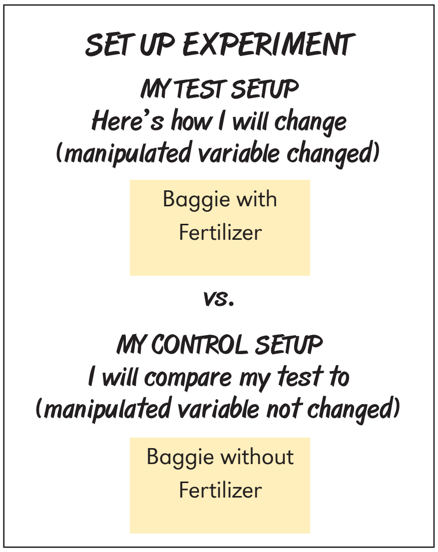
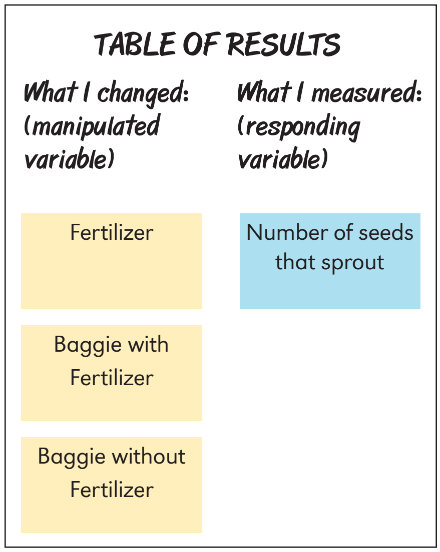


Figure 7.

Table of Results.



When students are asked what they will compare their results to, they recognize the need for a comparison or a *control setup*. In this case, the comparison baggie has no fertilizer, but the amount of water in the baggie is the same as in the one with fertilizer. In most cases the teacher can use the original baggie garden used to initiate the brainstorming (before anything was changed) as the control baggie.

We have found that while the words *control* and *controlled variables* are sometimes confusing for students, they intuitively understand that the distinction between a test setup and a control setup is the manipulated variable; everything else is kept the same (as much as possible). Another, perhaps less confusing term for the control setup is *comparison setup*. Having students draw a diagram of each baggie garden in their experiment in their journal also helps them to keep track of the experiment.

Table of Results

Once the experiment is set up, students record observations. Identifying the manipulated and responding variables is central to constructing a data table. Using the Table of Results inquiry board (Figure 7), students see that a *data table* consists of a clearly labeled manipulated variable column (e.g., yellow self-stick note—fertilizer) where all experimental baggies are listed (e.g., baggie with fertilizer, baggie with no fertilizer). The responding variable (e.g., blue note—number of seeds that sprout) identifies the column where the results can be recorded. Students may need to add additional columns if more than one observation is planned (i.e., for subsequent days) or for notes to record other interesting observations (such as the size of the sprouts). Once the experiment is in progress, students often notice other, important things to record. This is a natural part of experimental science when the effect of the manipulated variable isn't known.

Look for Patterns and Graph of Results

After the experiment is completed, students represent their important results in a graph that also reflects the relationship between the manipulated variable (what was changed) and the responding variable (what was measured) (Figure 8). By convention, the *Y*-axis represents the responding variable (e.g., blue self-stick note) while the manipulated variable (e.g., yellow self-stick note) is placed along the *X*-axis. A graph is not an end in itself; it is a visual presentation of the patterns or trends in the data and an important tool for answering the original question.

Students often need help deciding when to use bar graphs or line graphs, selecting the proper scale, labeling the graph correctly, and evaluating whether the graph makes sense. For example, if, with the fertilizer example, students find that the same number of seeds sprouted with and without fertilizer, ask students how they may represent the data. Ask students how they recorded it in their notebooks/journals. Then discuss the value of each way. If students do not have experience constructing their own data tables or graphs, propose two different types (e.g., line graph and bar graph) and draw blank ones on the board or overhead. Ask students to label and fill in the graphs. Then discuss which one is more clear or efficient. In this case, a line graph would not convey much information. A bar graph showing equal numbers of germinated seeds might be easier and clearer.

Figure 8.

Look for Patterns and Graph of Results.

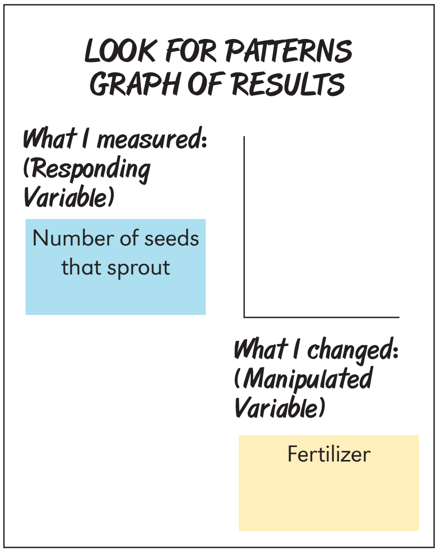
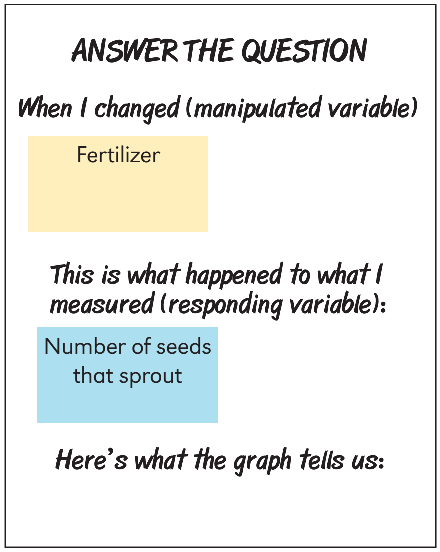


Figure 9.

Answer the Question.



Answer the Question

To complete the experiment, students use their data table and graph to answer their original experimental question. This inquiry board (Figure 9) reminds students that their experimental question asked about the effect of the manipulated variable on the responding variable. In most cases, attempting to answer the original question will generate more questions. But this is the nature of science, isn't it? Investigations are seldom completed with just one experiment, no matter how well designed. Rather, investigations are compiled of ongoing experiments that build on each other as "truth" about a particular phenomenon. Students can be invited into this exciting adventure, but we must help them understand the logical flow of an experiment.

From the question to the answer, an experiment explores the effect of a manipulated variable on an outcome. Using colored self-stick notes to represent the manipulated and responding variables helps students visualize this flow. Inquiry boards are not intended as a prescription for the "scientific method" but rather are tools for helping students understand the relationship of variables in an experiment. Inquiry boards help students brainstorm the many possible variations in a simple experimental protocol such as a baggie garden. It helps students recognize that every single variation represents a possible manipulated variable and that by manipulating only one variable at a time, the experimenter can measure the impact of that variable on the outcome (i.e., the responding variable).

There are many experimental scenarios that work well with the inquiry board technique. For example, students might start with a standard cookie recipe as control, then design experiments to find out how different ingredients or procedures affect the recipe's outcome. Scenarios that seem to work best are those that take an already established experimental technique or setup (such as the baggie garden) and then allow students to brainstorm possible ways to vary the procedure to design their own investigation. With practice and the inquiry boards for guidance, students will begin to design investigations with ease. ■

Connecting to the Standards

This article relates to the following *National Science Education Standards* (NRC 1996):

Content Standards

Grades K–8

Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry

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Resources

Goldworthy, A., and R. Feasey. 1997. *Making sense of primary science investigations*. UK: The Association for Science Education.

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academy Press.