From Cookbook to Experimental Design

A concrete strategy to help students learn to design investigative questions

By Jenny Sue Flannagan and Rachel McMillan

Bobby Flay, Giada DeLaurentis, and Mario Batali are well known for their culinary talents. They are masterful chefs who are experts at mixing spices with food to create extraordinary dishes. While they have honed their craft, they once were novices in the cooking world. Time, patience, and learning from experts in the field helped them to develop their skills.

Developing expertise, whether from cook to chef or from student to scientist, occurs over time and requires encouragement, guidance, and support. One key goal of an elementary science program should be to move students toward expertise in their ability to design investigative questions. The ability to design a testable question is difficult for novice science students and requires teachers to support students by using concrete strategies. This article promotes a tangible strategy teachers can use to help students design testable questions for experiments and discusses how the strategy can be used to help students design their own investigative questions.

Figure 1.

The Four-Question Strategy (Original).

Question 1:	What materials are readily available for conducting experiments on ____________________?
Question 2:	What does __________do? How does it act?
Question 3:	How can I change the set of ________ materials to affect the action?
Question 4:	How can I measure or describe the response of __________ to the change?

COTHRON, GIESE, AND REZBA (2000) P. 28

Figure 2.

Materials lists for Question 3.

Question 3 (The Cause Question) from Jenny Sue's class:

How could we change the following materials to affect how the car rolls?

Ramp	Car
Height of ramp*	Weight of car
Surface of ramp	Color of car
Length of ramp	Brand of car

Question 3 (The Cause Question) from Rachel's class:

How could we change the following materials to affect how the Alka Seltzer tablet dissolves?

Alka Seltzer Tablet	Liquid
Size of tablet	Color of liquid
Brand of tablet	**Temperature of liquid***
Surface area exposed	Type of liquid
	Amount of liquid

* selected variable to change

Structured, Guided, and Beyond

Teachers can facilitate this process by starting with structured inquiry experiences and demonstrations. Structured inquiry experiences model all the right things for the students: questions that drive the inquiry process, data tables to record observations, and graphs that visually display the data. Demonstrations provide teachers with an opportunity to think aloud the types of questions that can be asked and then identify the features that make a question investigative in nature.

For example, in viewing a demonstration in which dry ice is added to a cup of cold water with soap, students observe that it takes a while for bubbles to form. The next day, the teacher could bring up the demonstration and ask, "Remember yesterday's demonstration, when we put dry ice in the cold water that had soap in it? I wonder if changing the temperature of the water would make a difference in the time it takes for the bubbles to form?" This is an opportunity to discuss that this is a *testable* question because they would be changing or manipulating something about the physical property of water—the temperature.

We believed that we were developing young scientists because we were using structured inquiry experiences and demonstrations such as those described above. However, over time we came to realize that demonstrations and structured inquiry experiences alone—"cookbook labs" in which students always follow a recipe—did not provide students with a framework for developing their own testable questions. In fact, if anything, we realized that only engaging students in structured inquiry made students dependent learners, when in essence we were striving to develop a student's ability to design a question on their own.

We began looking for a strategy that would help us. We found one such strategy (Figure 1) in the book *Science and Research—Practical Strategies for the Science Classroom and Competitions* (Cothron, Giese, and Rezba 1989). This four-question strategy is a brainstorming tool to help students generate a testable question for an experiment. The strategy asks students to identify a topic, such as plants, and then brainstorm what materials they would need if they were going to conduct an experiment on plants (Question 1). Next, in Question 2, the students think about the action (what plants do). Most students generate ideas like "they grow," "they die," and "they can bend." In Question 3, students pick one action and think about how they could change the materials to affect the action they selected. For example, if a student picked "plants grow," they would then think about how they could change water to affect how plants grow. Lastly, in Question 4, students consider how they can measure or describe the response of the plant to the change in material from Question 3. The strategy seemed logical, and we were eager to try it in our elementary classrooms.

The Original Model

I tried the strategy in my fifth-grade classroom, and my coauthor, Rachel, used the strategy with her sixth-grade students. Following the objectives from our curriculum units, my lesson was designed around ramps (as our class was studying motion), while Rachel's lesson focused on temperature and its effect on solids. In previous years, we taught these lessons using the structured inquiry labs from our curriculum guide. The fifth-grade experiment asked students to determine what would happen to the time it took a car to roll down a ramp when the height of the ramp was changed. In order to use the new four-question strategy with this lab, I assumed I just needed to start by asking my students what materials they would need to design an experiment using ramps (i.e., Question 1). Similarly, the lab from Rachel's curriculum was one that involved students observing how fast an Alka Seltzer tablet dissolved when you changed the temperature of water. Rachel began her lesson by asking her students what materials they would need to design an experiment using Alka Seltzer.

While we were in two different classrooms, we had the same reaction from our students: confusion, questions, and in some cases, tears. Students just could not figure out where we were going with our questions. We tried to rephrase the questions in a way that would guide them, but ultimately we ended up modeling the process for them.

When Rachel and I met later that afternoon and compared notes on trying out the strategy, it dawned on us that perhaps students could not answer Question 1 because they didn't have experience with the objects we were asking them to design an experiment around. We decided to modify the strategy by switching the order of Questions 1 and 2 and also incorporating time for students to explore the materials first. In other words,

Figure 3.

Experimental design planning template.

Complete the planning template before beginning the lab.

1. Research Title:

____
____
____

2. ***What are you changing in your experiment*** (THE "CAUSE")? This is the ***independent variable.*** Pick **one** item from question #3. (This will be the "if" in your hypothesis.)

____
____
____

3. ***What is being measured*** in your experiment (THE "EFFECT")? This is the ***dependent variable.*** See question #4. (A prediction of how this experiment will turn out will be the "then" in your hypothesis.)

____
____
____

4. **Hypothesis:** (Use an "if…then…" format)

____
____
____

5. What must you ***keep the same*** in your experiment? These are the ***constants*** in the experiment. These will be everything else from question #3.

____
____
____

The purpose of this experiment is to determine the effect of

__________________________ on ________________.

(Independent Variable from question #2 above) **(Dependent Variable from question #3 above)**

Get your teacher's approval before beginning your experiment.

Figure 4.

Student self-assessment rubric.

I wrote a testable question	YES	NO
I identified the independent and dependent variables.	YES	NO
I identified the constants and made sure they stayed constant in my experiment.	YES	NO
I did a fair test	YES	NO
I recorded my data	YES	NO
I made a picture with labels and detail	YES	NO
I used science words to explain what I learned	YES	NO
I understand what I learned	YES	NO
I have a new question	YES	NO

we decided we would provide the materials they would be using to brainstorm ideas about so they could play with them in order to generate a list of actions. These simple changes ended up making all the difference in the world!

The Modified Model

We tried the activities a second time, following our new modified model:

Exploration: Have students play with the materials

Question 1 (Observing Actions Question): What did the ___________do? How did it act? List all the actions you observed.

Question 2 (Listing Materials Question): If we were going to design an experiment around the action of _________________, what materials would you need?

Question 3 (The Cause Question): If you have the following materials, what could you change in order to see if it affects how the _________________________?

Question 4 (The Effect Question): How could we measure the change if ___________ affects how __________acts? Think about measuring tools we use or observations we could collect.

Question 1: Observing Actions

The second time, I began the lesson by letting the students explore, for 5–10 minutes, how cars behaved when they went down a ramp. Afterward, when I asked students what toy cars do (Question 1, Observing Actions), they responded with action words like *roll, crash, flip,* and *break*. Similarly, Rachel gave her students 10 minutes to observe what an Alka Seltzer table does when it is put in water. Again, just like my students, Rachel's students were able to generate a lot of actions, such as *dissolve, fizz,* and *break*.

Next, we guided the students to pick *one* action word from the list generated in Question 1. My students chose the action of rolling while Rachel's class chose the action of dissolving.

Question 2: Listing Materials

Once students had selected one action, this action was then used with Question 2 (Listing Materials). We began by asking students to brainstorm materials they would need if they were going to design an experiment around their chosen action word—in my class, students brainstormed materials they would need if they wanted to design an experiment around rolling cars (toy cars, ramps, books, timer); in Rachel's class, students brainstormed the materials they would need if they were going to design an experiment around dissolving Alka Seltzer tablets (cup, Alka Seltzer, liquid).

Question 3: The Cause

The next step in the process was to generate the potential independent variable for the experiment. This occurs as part of Question 3 (The Cause Question). In this step, students brainstorm what they could change about each of the available materials to see if it would have any effect on the action selected in Question 1. To guide students, we gave students a table with the materials available (Figure 2, p. 47). We prompted students to focus on the properties of the objects.

In my class, students suggested possible changes that could affect the action of rolling, such as changing the height of the ramp, changing the surface of the ramp, changing the type of car used, and changing the weight of the car. In the sixth-grade class, students suggested changing the type of liquid the Alka Seltzer tablet was placed in, changing the amount of liquid, changing the color of the liquid, changing the temperature of the liquid, and changing the size of the Alka Seltzer tablet.

Once the students had finished sharing their ideas, we guided the students to pick only *one* property to change (shown in bold on Figure 2, p. 47)—for example, in my class we agreed to change the height of the ramp; and in Rachel's class students decided to change the temperature of the liquid.

Question 4: The Effect

Next, students brainstormed ways to measure the effect of that change—Question 4 (The Effect Question). We asked students to think about what they could observe or measure, using tools, to tell us if changing the one property affected how that object acted. In my class, students decided to measure the time it takes the toy car to travel down the ramp; in Rachel's class, students decided to measure the time it took for the tablet to dissolve.

Generating the Testable Question

The last step in the process was to generate the question based on the brainstorming process. To do this, we gave students the following question to plug in: We are going to design an experiment to test if changing the (*height of a ramp*) affects the (*time it takes for the car to roll down the ramp*).

To help students plan out their experiment and to understand that scientists, in an effort to design a fair test, must only manipulate one variable, we designed an experimental design template (Figure 3, p. 48) and worked with students to identify the independent and responding variables, constants, and so on. Ultimately, students used the template to design their own testable question.

We discussed that anything brainstormed in Question 3 (The Cause Question) has the potential to become an independent variable. Once an item is chosen from Question 3, then the rest of those properties must be held constant in order to have a fair test. So in other words, we could not change the height of the ramp *and* change the type of car.

With the experiment plans set, students, armed with stopwatches and ramps all over the room, measured the time it took for a car to travel down the ramp at the heights of 10 cm, 20 cm, 30 cm, and 40 cm. Students found out the higher the ramp, the shorter the time it took the car to travel down the ramp.

Students in Rachel's class learned the warmer the water was, the faster the tablet dissolved. This result inspired students to try another experiment. They went back to the variables in Question 3, and this time students selected to change the type of liquid. Students learned through this second experiment that more acidic liquids help to dissolve the tablet faster as well.

Lessons Learned

After students completed their experiments, they assessed themselves using a list of seven simple questions (Figure 4, p. 49). This allowed them to reflect on their design and make sure they paid attention to changing one variable. We used the same form to assess the students, giving us both a chance to discuss with students their strengths and areas in need of improvement.

Using this method, we found that as the school year progressed, students developed into effective problem solvers as they directed, monitored, and evaluated their own learning and progress. Even the most reluctant science learners gained confidence and were motivated to engage in science activities. With modeling and practice, the four-question strategy has enabled our students to develop investigative questions and to become successful as scientists. While they may not be experts like Albert Einstein or Rachel Carson yet, they are certainly on their way moving from student to scientist! ■

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Reference

Cothron, J.H., R.N. Giese, and R.J. Rezba. 1989. *Science and research—Practical strategies for the science classroom and competitions*. Boston: Kendall/Hunt.

Connecting to the Standards

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

Content Standards

Grades 5–8

Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry

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