GUIDING STUDENTS INTO INQUIRY

Most students, and teachers for that matter, are not ready to begin with full student inquiries at the start of the school year. During the first few weeks of school, teachers need to set expectations for classroom management, discipline, classroom routines, grading procedures, and so on. Establishing and maintaining a healthy and safe classroom is a prerequisite for an inquiry lesson. Without rules, inquiry lessons become unruly and unmanageable. It is normal for teachers to wait until they grow accustomed to their classes before starting a full inquiry-based unit. This is especially true for teachers who have students coming to them without prior experience in inquiry learning.

For those reasons, the "Invitation to Inquiry Grid" (Figure 5.1) can also serve as a way to plan instructional units so that students are gradually but continuously encouraged to take on more responsibility for their learning. During the early months of the school year or when students are unfamiliar with inquiry learning, the teacher may choose to begin with the demonstration mode, focusing on having students observe and experience discrepant events. During the next several months, the teacher can then move into the activity stage, concentrating on providing sound hands-on activities that provide the opportunity for extension investigations. By midyear, a reasonable expectation would be to have students involved in one or more teacher-initiated inquiries, with the goal of evolving the students' expertise into several full student-initiated inquiries before the end of the year.

The "Invitation to Inquiry Grid" can also be used as a monitoring tool for teachers in designing their year-long instructional plans. As the school year proceeds, teachers can ask, "Am I moving my students from teacher-dependent to more independent experiences, and am I providing opportunities for student-initiated inquiries as the year goes on?"

By now, you should have a good grasp of the difference between doing hands-on science and inquiry-based investigations. You have read that although most inquiry investigations involve using hands-on and manipulative means of learning, not all hands-on activities are inquiry-based. When a hands-on activity poses the question to the students and also tells the students what materials to use and how to go about finding the answer to the question, it is not inquiry.

To further explain the differences between a demonstration, a traditional laboratory activity, a teacher-initiated inquiry, and a student-initiated inquiry, a lesson on soil permeability will be presented in four different ways. Using the same concept, we can then see how each stage differs from one another. Let's suppose, in a high school earth science class, we wanted to find out the drainage rates of different types of soil.

As a demonstration lesson, the teacher probably would be standing in front of the class behind a demonstration table, posing the question, "How does the type of the soil determine the drainage of water through the soil?" The teacher would then show and describe the supplies and materials to be used in the demonstration. Following the outlined steps of the procedure, the teacher would set up the materials as follows.

The teacher inserts a piece of filter paper in a large funnel that is held above a collecting beaker. The teacher then measures a given amount, say 200 grams, of a soil sample and places the soil sample into the funnel. Then the teacher uses a graduated cylinder to measure 100 mL of water and pours the water over the soil sample in the funnel. As the water seeps through the soil sample, some of the liquid will drain through the bottom of the funnel and drip into the collecting beaker. At the end of

5 minutes, the teacher measures the amount of water in the collecting beaker and records the results on the board. The teacher then goes on to test other samples of soil, clay, sand topsoil, and so on. At the conclusion of the demonstration, the teacher summarizes the data, plots it on a bar graph, then describes to the students the relationship between the soil and the amount of water that drained through the sample. Depending on the teacher and the class, questions from the students might arise from the demonstration. Because this demonstration does not represent a discrepant event, the teacher may choose to pose "going further" or extension-type questions to the class or may end the demonstration without further discussion. The demonstration may take from 30 to 45 minutes.

In a traditional laboratory activity lesson, the teacher would have the students at tables in small groups of three or four. A worksheet would be distributed to each of the groups, and the teacher would provide an overview or prelab the activity. The teacher would go over the procedure by reading the directions and answering any questions about the procedure. The question to be studied would be provided to the students on the laboratory worksheet, along with a list of the supplies and materials needed and the steps to follow in the procedure. A typical laboratory may look like this:

Question: How does the type of soil affect the drainage rate of water?

Materials:

- Four samples of soil (examples: topsoil, clay, sand, loam, peat moss)
- Ring stand and ring clamp
- 250-mL beakers
- Large funnel
- Filter paper or coffee filters
- Graduated cylinder
- Water
- Triple-beam or electronic balance

Procedure:

1. Set up the ring stand as shown.
2. Place a large funnel in the ring clamp.
3. Fold a piece of filter paper to fit within the funnel.
4. Place a collecting beaker under the funnel.
5. Measure 200 grams of topsoil.
6. Place the 200-gram sample of topsoil in the funnel.
7. Measure 100 mL of water.
8. Pour the 100 mL of water into the funnel over the topsoil sample.
9. Wait 5 minutes.
10. Measure the amount of water in the collecting beaker. Record your results.
11. Repeat the procedure for three other types of soil.

As the students work on the lab, the teacher circulates among the groups and provides assistance in answering their questions. In completing this activity, the students experience a hands-on science lesson with many opportunities to observe, make mathematical measurements, manipulate materials, record data, and draw conclusions. The activity is an excellent way to get students engaged in doing science and may take between 30 and 45 minutes to complete.

In a teacher-initiated inquiry, the teacher would pose the question, "Does the type of soil affect the drainage rate?" and challenge students to formulate a procedure to answer the question. The teacher would have four or five different soil samples available, some with large particles and some without. The students would be encouraged to write a hypothesis and a plan to test their prediction. Once the plan was completed, the students would be free to get whatever materials they needed to carry out their plan and collect evidence to test their hypothesis. The teacher may choose to substitute a 2-liter plastic bottle for more expensive equipment and glassware.

During this time, the teacher would circulate from group to group and listen in on their discussions. The teacher would be aware of comments made by the students that would reveal any misconceptions about drainage rates and provide additional prompts to test the misconceptions. The teacher would pose further questions for the students to consider and have additional inquiries available for those groups who completed their investigation early.

In a student-initiated inquiry, the teacher could assess prior knowledge and uncover misconceptions by asking students to share what they already know about soil and drainage rates. The teacher may choose to record their experiences by listing them on the board or on an overhead. Next, the teacher would allow time for self-directed exploration in which students observe drainage patterns with different soils. During this exploration stage, the teacher would encourage students to raise their own personal questions and inquiries about drainage rates and suggest that they phrase their inquiries as "What if," "I think," or "I wonder" statements. Depending on the preferences of the class, the teacher could again ask the groups to share their questions while making a list of their questions on the blackboard or on an overhead. Following this exercise, the teacher would identify each question as

- one that is ready to be answered through an investigation,
- one that needs to be revised and/or rewritten before it can be investigated, or
- one that requires an outside "expert" or resource to answer.

It is important for students to classify their questions into these categories to further understand the direction their questions will take them. For example, questions starting with "why" usually require an explanation to answer. These "why" questions often need to be revised into "what" or "what if . . ." questions before they can be investigated.

Sufficient materials and supplies should be available at a supply center for groups to use as needed. The students would brainstorm ways to solve their question and then go about carrying out their plans. The teacher would rotate from group to group, asking more questions and clarifying students' ideas and prior conceptions about the soil samples. The teacher would encourage the groups to write down and investigate other questions that come up during the course of their investigations. At the end of the lesson, the teacher would bring all the groups together so they could share their observations and conclusions. Each group would be given time to get up in front of the class and state the question they investigated and the results they discovered, as well as to apply the phenomenon studied to situations outside the classroom.

Each of the four levels of instruction has definite advantages and disadvantages, and of course each teacher could plan and implement the lesson differently from the way expressed here. Demonstrations greatly reduce the time requirement and ensure that each student has the same opportunity to observe the same concept being studied in the same way. The traditional laboratory format allows the teacher to have all the students arrive at the same conclusion together. This may be useful when introducing a specific concept when you want all students to come away with the same information. Activities usually are very structured and, except for any extension questions that may come about, are very straightforward and limit creativity. Teacher-initiated inquiry is a good instructional strategy for getting students to consider ways to plan and solve questions. Student-initiated inquiries take an extended amount of time. Often the teacher may not know where the students' questions will take them. These inquiries, however, provide a means for students to empower themselves by directing the course of their own work.

The four stages are summarized in Figure 5.4.

Figure 5.4 Expanded Invitation to Inquiry Grid

	Demonstration	Activity	Teacher-Initiated Inquiry	Student-Initiated Inquiry
Posing the Question	Teacher	Teacher	Teacher	Student
Planning the Procedure	Teacher	Teacher	Student	Student
Formulating the Results	Teacher	Student	Student	Student

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	Demonstration	Activity	Teacher-Initiated Inquiry	Student-Initiated Inquiry
Starter Question	Predetermined	Predetermined	Posed by teacher	Generated by student
Plan or Procedure	Predetermined	Predetermined	Designed by student	Designed by student
Outcome	Predetermined	Expected	Guided toward a concept	Open-ended

(Continued)

Figure 5.4 (Continued)

	Demonstration	Activity	Teacher-Initiated Inquiry	Student-Initiated Inquiry
Time	5–30 min.	30–60 min.	45–60+ min.	60–120+ min.
Role of Teacher	Active	Provides direction	Guide/facilitator	Facilitator
Role of Student	Observer	Follows direction	Problem solver	Investigator
Materials	Provided	Provided	Suggested	Suggested
Content	Focused	Focused	Needs some focusing	Requires focusing

In this chapter, we have looked at ways to categorize science experiences ranging from demonstrations to student-initiated inquiries. As the teacher designs his or her year-long plans, the Inquiry Grid can serve as a way to move students toward more self-directed experiences. If the goal of your science program is to provide students with opportunities to engage in inquiry, planning a gradual shift from left to right in the Inquiry Grid will become a means to ensure that your students develop investigation skills throughout the school year.

EXTENDED INQUIRIES: A CASE STUDY IN BOTTLE ECOSYSTEM

Not all scientific inquiries are designed to be completed in one or two classroom periods. Inquiry investigations can be protracted and sustained over several months or even the entire school year. Knowing that biology students have an interest in plant and animal interactions, an experienced biology and environmental science teacher, Jay Costanza, uses and recycles 1-liter plastic soda bottles to engage his 10th- and 11th-grade biology students in designing environments for observing ecological interactions and succession over an extended time.

Jay is a veteran teacher of 15 years and has been teaching through inquiry-based strategies his entire career. With a background in project-based instruction, Jay teaches biology, environmental science, and Advanced Placement biology at School of the Arts, a midsized urban high school that specializes in the arts and drama performance. Bringing biological concepts and the human body, especially the muscular and skeletal systems, into the arts and dramatic theater has always seemed like a natural link to Jay. He also involves his students in an Adopt-a-Stream program; they take samples from a nearby creek to test and monitor water quality and assess the overall health of the creek over time.

At School of the Arts, building a *culture of inquiry* is an extension of the school's vision and philosophy. Because biological inquiries, like succession, are inherently longer, Jay designs the course curriculum from the macroscopic level (ecology) to the microscopic level (cell biology and genetics), with students beginning their extended inquiry into ecology during the first week of school. By beginning the biological and ecological inquiry in September, Jay feels he establishes a *tone* for the remainder of the year while introducing students to the theme of interdependency and succession.

Using the book *Bottle Biology* (Ingram, 1996), Jay introduces students to the idea of inquiry at the start of the school year. He initiates this low-cost inquiry with two essential starter questions: (a) What are the life processes that are essential to all living organisms? (b) What are the conditions to sustain life? He does this by first providing a scenario where students design a biosphere on the surface of Mars, then later has students apply their research in designing an actual plastic bottle ecosystem.

The Bottle Ecosystem unit aligns to the *National Science Education Standards* (NRC, 1996) for grades 9–12.

Science as Inquiry Standard

Students will

- Identify questions and concepts that guide a scientific investigation. (p. 175)
- Design and conduct a scientific investigation. (p. 175)
- Use technology and mathematics to improve investigations and communications. (p. 175)
- Formulate scientific explanations and models using logic and evidence. (p. 175)
- Communicate and defend a scientific argument. (p. 176)

Life Science Content Standard

As a result of activities, all students should develop an understanding that

- Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers. (p. 186)
- Organisms both cooperate and compete in ecosystems. The interrelationships and interdependence of these organisms may generate ecosystems that are stable for hundreds or thousands of years. (p. 186)

Science and Technology Standard

As a result of activities in grades 9–12, all students should

- Identify a problem or design an opportunity,
- Propose designs and choose between alternative solutions,
- Implement a proposed solution,
- Evaluate the solution and its consequences, and
- Communicate the problem, process, and solution. (p. 192)

To start the extended inquiry, Jay arouses students' curiosity by first posting a large picture of the surface of Mars in the front of the room. As students enter the classroom on Day 1 of the inquiry, a video from the Discovery Channel is showing mechanical robots collecting rock samples from the surface of the Red Planet. As the students settle into their seats, Jay begins. "What is life?" he asks. "What is a living thing?" Holding a rock in one outstretched hand and a piece of coral in the other, he asks, "Is this rock alive? Is this piece of coral alive?"

After a brief discussion on the meaning of life, Jay continues. "If you were to live on Mars for an extended amount of time, what would you need to survive? Can you think of a time in your life when you were far away from home and felt extremely cold, thirsty, lonely, or frightened? What did that feel like? Now imagine being an astronaut on the surface of Mars where there is no air, food, water, warmth, plants, or other animals. How could you survive? What would you need to stay alive?" As Jay walks about the room, he continues, "We have been given a special assignment by NASA. Your task is to design a biosphere that would sustain humans living on the surface of Mars for 18 months. I will now pass out the letter from NASA and you can read it quietly to yourself." The letter reads:

> Date: September 10, 2003
> To: The Biology Students in Room 246
> From: Dr. Sharon Austin, Director of Destination Mars
>
> Congratulations! Your class has been selected to participate in a secret program for NASA named Destination Mars. Because our government is considering the possibility of establishing a colony on Mars, your mission is to design a biosphere that will allow a group of ten astronauts to survive on the plant Mars for eighteen months. Your first assignment for Destination Mars will be to gather members of a team and form a "think tank." The objective of the think tank is to decide what is needed to sustain life on the planet Mars, ultimately making this program a success. You can submit your designs as a poster or electronically as a PowerPoint presentation.
>
> During the project, you will be briefed by your biology teacher, Mr. Costanza, as to the specifics of the mission. Good luck, and remember, the success of this program depends upon you!

Jay now makes online resources and books available to students regarding climate on Mars. Several students use the following NASA Web sites for obtaining information about Mars:

http://mars.jpl.nasa.gov/classroom/teachers.html

http://mars.jpl.nasa.gov/odyssey/

http://mars.jpl.nasa.gov/odyssey/overview/index.html

http://mars.jpl.nasa.gov/index.html

The students are given several days to do their research. Although some time is spent in the classroom, most of the students' research is done in the school library, online, or at home as homework. In class, teacher-led discussions focus on the two initial questions: What are the life processes that are essential to all living organisms? and What are the conditions necessary to sustain life?

After several days of researching information, the groups are ready to share their designs. One at a time, the groups come to the front of the class and present their projects. As they compare and contrast the designs, students discuss the similarities and differences among the groups.

Jay now informs the students that they will use the research they discovered about the needs of living organisms from the Mars project to build an actual living model of an ecosystem from 2-liter plastic bottles. He tells the students that not only will they identify what living things need; they'll have to prove it! "Your next responsibility as a research ecologist," Jay continues, "is to use one or more 2-liter plastic bottles to design a living chamber that will keep a fish or other animal alive for 3 months. You can use sand; gravel; small rocks; soil; snails; aquatic plants like duckweed (*Lemna*), fanwort (*Cabomba*), or hortwort (*Ceratophyllum*); and pond water to build your mini-ecosystem."

Actually, Jay knows that most containers will last longer than 3 months. In fact, some may last as long as 5–6 months, but that is all part of the inquiry, to keep students engaged and involved.

"You mean we have to design a container using plastic bottles to keep something alive for 3 months?" Eugene asks.

"That's impossible!" Karen adds. "Come on, how can we do that?"

"Well," Jay says, "start first with a fish, say a guppy, and then later consider adding other organisms like a worm or a cricket."

Another student asks, "What do guppies eat? What are we supposed to feed them? How do I find out what a cricket eats?"

"Well," Jay responds, "that's all part of being a scientist. We have to do research just like in the Mars project."

Students begin by brainstorming various designs to construct their bottle ecosystems. One group decides to place a hole in the top of the bottle to monitor temperature and dissolved oxygen, while another group centers on how to measure the pH of the water. During the class's brainstorming and design sessions, Jay provides past copies of *Carolina Tips* (a product magazine from the science supply company Carolina Biological Supply) and the *Wisconsin Fast Plants* Web site (www.fastplants.org/home_flash.asp) as resources. Students also use other online resources to research their designs. For the remainder of the period and into Day 2, the teacher conveys additional parameters of the investigation. He tells the students they can experiment with their bottle designs for several weeks to determine what works and what doesn't work. Then, after 3 weeks, the containers will be sealed, with nothing new to be added. "That's when the 3-month clock starts ticking," he informs the class. Jay then provides aquarium books, Internet resources, scientific magazines and journals, biology textbooks, and other sources for the groups to research the needs of living things.

Students are instructed to place their research notes and designs in their journals, including a diagram and explanation of "How my bottle ecosystem works." The bottle designs vary. Some students choose conventional systems, while others choose to connect two bottles, with one ecosystem supporting another.

Each day, the students continue to enter their observations and drawings in their journals. As groups brainstorm their ideas, several students make concept maps to describe what a fish or a guppy needs to survive. One student's entry indicates, "I found out that fish feed on elodea. That may significantly improve its chances for survival." Students consider other fish they are familiar with, such as goldfish or betta fish.

After several days, students share their bottle designs by making posters from their journal entries. Their prototypes enable them to test their ideas and share their designs in front of the class. Jay tells students that by sharing their models and ideas, they should discuss limiting factors such as space, temperature, breeding concerns, and even the interactions among the organisms in the ecosystem.

Some groups choose plants like grasses, while one selects green beans as their food supply. During the discussion, one group mentions that it plans to place tap water in the bottle; another plans to get pond water. Other discussions center on the type of soil to use—dirt versus clay or sand. Others share research discoveries regarding the feeding habits of guppies, crickets, and earthworms. The teacher concludes the period by reiterating that the project is an inquiry into a design of trial and error.

Later in the week, the teacher introduces the class, by means of a formal presentation, to the carbon dioxide/oxygen cycle and nitrogen cycle. During the presentation, concepts including biosphere, abiotic and biotic factors, ecosystem, community, habitat, producer, and consumer are discussed. Jay asks the following questions: "Why is your ecosystem considered a closed system, why did we use a closed system for this activity, and why is light required in the bottle ecosystem?"

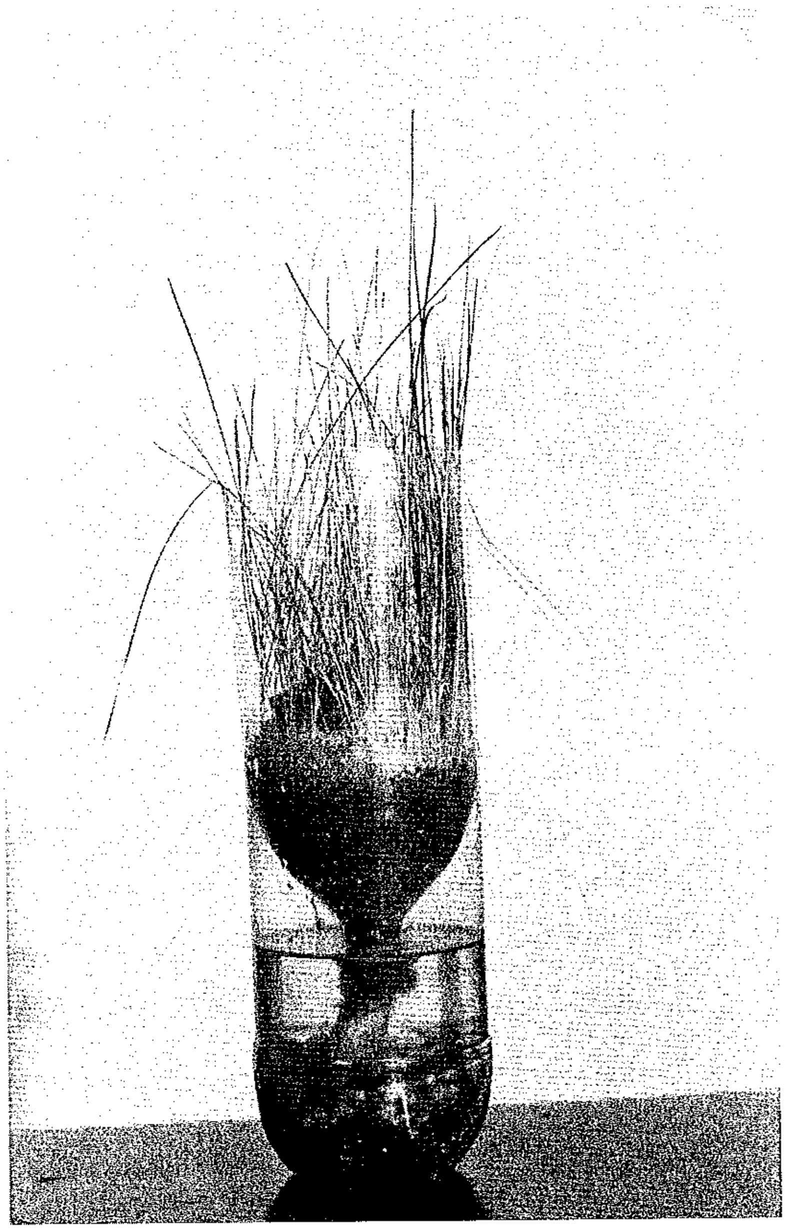
Now, the inquiry turns its attention toward discussing how students would monitor pH, temperature, and dissolved oxygen rates. Some students suggest using probes and spreadsheets to collect and record data over the 3 months.

By this time, students are eager to begin construction in their bottle ecosystems. At the start of Day 6, students use their scale drawings from their journals to cut plastic bottles and assemble their ecosystem structures, as shown in Figure 5.5.

Figure 5.5

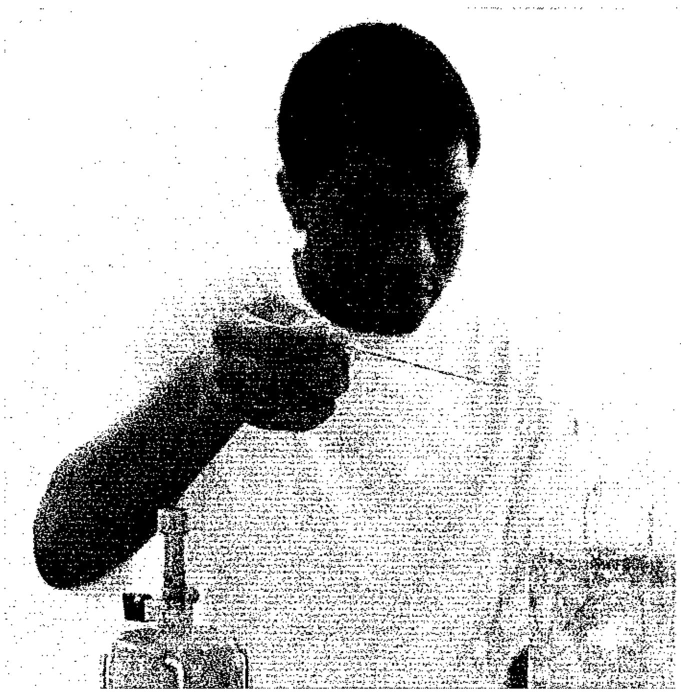
Upon completion, the students add the fish, plants, and other organisms to the container, creating ecosystems similar to the one shown in Figure 5.6. For 2 weeks, the students daily observe the bottle environment, monitor the conditions, and record appropriate data. They update spreadsheets and record notes in their journals. The students now have 2 weeks to observe their structure and make modifications. During this time, students assess, through trial and error, the capacity of their structure to sustain life over an extended period of time.

Figure 5.6



During this 2-week experimentation period, some students discover that food supplies are not sufficient for all the organisms, and thus make revisions to their model. Others conclude that crickets have difficulty existing in a confined chamber without constant addition of a food supply. All these conclusions eventually result in revisions in the structure of the experimental chamber or changes in the choice of organism to be placed in the structure. Also during the 2-week experimentation period, Jay uses the ecosystems to introduce students to cloning. He conducts a lab using the Introduction to Cloning Kit: Duckweed, produced by Ward's Natural Scientific, because many of the students used duckweed in their bottle ecosystems.

Figure 5.7



After 2 weeks, the ecosystem containers are closed.

At the completion of the Bottle Ecosystem investigation, all students are expected to be able to do the following:

- Explain why their structure is considered a closed ecosystem
- Identify biotic and abiotic factors in their ecosystems
- Identify the following organisms in their ecosystem: producer, primary consumer, and decomposer
- Explain how carbon, oxygen, carbon dioxide, nitrogen, and water are cycled through their ecosystem
- Create a diagram of a food chain or energy pyramid and a food web from their ecosystem

AN INTERVIEW WITH JAY COSTANZA

How would you describe your approach to teaching?

Jay: In both my high school and AP biology classes, my approach focuses on piquing students' interest in science and having them enjoy learning science. I also want students to be able to apply what we learn in the classroom to situations in the real world and maybe even consider science as a career. What I keep in mind is that kids are often interested in science at the earlier grades, but that enthusiasm seems to

QUESTIONS FOR REFLECTION

1. How would you describe Jay Costanza's approach to teaching?
2. What are the benefits of engaging students in extended investigations?
3. What are the benefits of engaging students in extended investigations that integrate biology with other areas of science, like space science?
4. In your experience, what helps students sustain engagement in extended, ongoing investigations?
5. In the Bottle Ecosystem case study, the teacher wanted to "set the tone" or "climate" for inquiry at the beginning of the school year. What are some advantages and disadvantages to using this approach so early in the school year?
6. What content and skills should be included in the student assessment at the end of the Bottle Ecosystem investigation? How would you assess the content and skills you identified?
7. How could you use the students' journal entries as part of an assessment?
8. How do you lead students through an extended investigation like the Bottle Ecosystem with little prior experience in inquiry?
9. Given that this is an extended inquiry lasting several months, would you assign pairs to work together, or instead have students choose their own partners?