Everyday Life Science Mysteries

Stories for Inquiry-Based Science Teaching

Richard Konicek-Moran

NSTA press
National Science Teachers Association

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Richard Konicek-Moran, EdD
Professor Emeritus
University of Massachusetts
Amherst

Botanical illustrations by
Kathleen Konicek-Moran

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The Stories and Background Materials for Teachers

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Finally I would like to dedicate these words to all of the children out there who love the world they live in and to the teachers and parents who help them to make sense of that world through the study of science.

Preface

Perhaps because everyone has so much interaction with the biological world around them, most people feel fairly secure about teaching the biological sciences. Patterns, processes, and relationships among living things form the basis of biology, the study of life. Since biological beings can range from single cells to the entire biosphere, children must be prepared to study the relationships among the various organisms, populations, and ecosystems we find on Earth.

And since so many of the organisms depend upon physical aspects of the environment, biology—like the other sciences—becomes multidisciplinary. They obey the laws of conservation of matter and energy (concepts found in *physics*) and engage in complex *chemical* reactions. They have evolved over eons and therefore are an integral part of the *geological* studies of the history of the Earth.

In the stories in this volume, you will visit the areas of heredity, botany, zoology, reproduction, physiology, reaction time, food, and life cycles. All of these stories correspond with the *scientific principles*, the *crosscutting concepts*, and the *core ideas* suggested and explained in the National Research Council's *A Framework for K–12 Science Education* (2012).

These stories are packaged in separate subject matter volumes so that those teachers who teach only one of the areas covered in these books can use them more economically. However, it bears repeating that the crosscutting concepts meld together the various principles of science across *all* disciplines. It is difficult, if not impossible, to teach about any scientific concept in isolation. Science is an equal opportunity field of endeavor, incorporating not only the frameworks and theories of its various specialties, but also its own structure and history.

We hope that you will find these stories without endings a stimulating and provocative opening into the use of inquiry in your classrooms. Be sure to become acquainted with the stories in the other disciplinary volumes and endeavor to integrate all the scientific practices, crosscutting concepts, and core ideas that inquiry demands.

Introduction

Case Studies on How to Use the Stories in the Classroom

I would like to introduce you to one of the stories from the first volume of *Everyday Science Mysteries* (Konicek-Moran 2008) and then show how the story was used by two teachers, Teresa, a second-grade teacher, and Lore, a fifth-grade teacher. Then in the following chapters I will explain the philosophy and organization of the book before going to the stories and background material. Here is the story, "Where Are the Acorns?"

Where Are the Acorns?

Cheeks looked out from her nest of leaves, high in the oak tree above the Anderson family's backyard. It was early morning and the fog lay like a cotton quilt on the valley. Cheeks stretched her beautiful gray, furry body and looked about the nest. She felt the warm August morning air, fluffed up her big gray bushy tail and shook it. Cheeks was named by the Andersons since she always seemed to have her cheeks full of acorns as she wandered and scurried about the yard.

"I have work to do today!" she thought and imagined the fat acorns to be gathered and stored for the coming of the cold times.

Now the tough part for Cheeks was not gathering the fruits of the oak trees. There were plenty of trees and more than enough acorns for all of the gray squirrels who lived about the yard. No, the problem was finding them later on when the air was cold and the white stuff might be covering the lawn. Cheeks had a very good smeller and could sometimes smell the acorns she had buried earlier. But not always. She needed a way to remember where she had dug the holes and buried the acorns. Cheeks also had a very small memory and the yard was very big. Remembering all of these holes she had dug was too much for her little brain.

The Sun had by now risen in the East and Cheeks scurried down the tree to begin gathering and eating. She also had to make herself fat so that she would be warm and not hungry on long cold days and nights when there might be little to eat.

"What to do ... what to do?" she thought as she wiggled and waved her tail. Then she saw it! A dark patch on the lawn. It was where the Sun did not shine. It had a shape and two ends. One end started where the tree trunk met the ground. The other end was lying on the ground a little ways from the trunk. "I know," she thought. "I'll bury my acorn out here in the yard, at the end of the dark shape and in the cold times, I'll just come back here and dig it up! Brilliant Cheeks," she thought to herself and began to gather and dig.

On the next day she tried another dark shape and did the same thing. Then she ran about for weeks and gathered acorns to put in the ground. She was set for the cold times for sure!

Months passed and the white stuff covered the ground and trees. Cheeks spent more time curled up in her home in the tree. Then one bright crisp morning, just as the Sun was lighting the sky, she looked down and saw the dark spots, brightly dark against the white ground. Suddenly she had a great appetite for a nice juicy acorn. "Oh yes," she thought. "It is time to get some of those acorns I buried at the tip of the dark shapes."

She scampered down the tree and raced across the yard to the tip of the dark shape. As she ran, she tossed little clumps of white stuff into the air and they floated back onto the ground. "I'm so smart," she thought to herself. "I know just where the acorns are." She did seem to feel that she was a bit closer to the edge of the woods than she remembered but her memory was small and she ignored the feelings. Then she reached the end of the dark shape and began to dig and dig and dig!

And she dug and she dug and she dug! Nothing! "Maybe I buried them a bit deeper," she thought, a bit out of breath. So she dug deeper and deeper and still, nothing. She tried digging at the tip of another of the dark shapes and again found nothing. "But I know I put them here," she cried. "Where could they be?" She was angry and confused. Did other squirrels dig them up? That was not fair. Did they just disappear? What about the dark shapes?

How Two Teachers Used "Where Are the Acorns?"

Teresa, a veteran second-grade teacher

Teresa usually begins the school year with a unit on fall and change. This year she looked at the National Science Education Standards (NSES) and decided that a unit on the sky and cyclic changes would be in order. Since shadows were something that the children often noticed and included in playground games (shadow tag), Teresa thought using the story of Cheeks the squirrel would be appropriate.

To begin, she felt that it was extremely important to know what the children already knew about the Sun and the shadows cast from objects. She wanted to know what kind of knowledge they shared with Cheeks and what kind of knowledge they had that the story's hero did not have. She arranged the children in a circle so that they could see one another and hear one another's comments. Teresa read the story to them, stopping along the way to see that they knew that Cheeks had made the decision on where to bury the acorns during the late summer and that the squirrel was looking for her buried food during the winter. She asked them to tell her what they thought they knew about the shadows that Cheeks had seen. She labeled a piece of chart paper, "Our best ideas so far." As they told her what they "knew," she recorded their statements in their own words:

"Shadows change every day."
"Shadows are longer in winter."
"Shadows are shorter in winter."
"Shadows get longer every day."
"Shadows get shorter every day."
"Shadows don't change at all."
"Shadows aren't out every day."
"Shadows move when you move."

She asked the students if it was okay to add a word or two to each of their statements so they could test them out. She turned their statements into questions and the list then looked like this:

"Do shadows change every day?"
"Are shadows longer in winter?"
"Are shadows shorter in winter?"
"Do shadows get longer every day?"
"Do shadows get shorter every day?"
"Do shadows change at all?"
"Are shadows out every day?"
"Do shadows move when you move?

Teresa focused the class on the questions that could help solve Cheeks's dilemma. The children picked "Are shadows longer or shorter in the winter?" and "Do shadows change at all?" The children were asked to make predictions based on their experiences. Some said that the shadows would get longer as we moved toward winter and some predicted the opposite. Even though there was a question as to whether they would change at all, they agreed unanimously that there would probably be some change over time. If they could get data to support that there was change, that question would be removed from the chart.

Now the class had to find a way to answer their questions and test predictions. Teresa helped them talk about fair tests and asked them how they might go about answering the questions. They agreed almost at once that they should measure the shadow of a tree each day and write it down and should use the same tree and measure the shadow every day at the same time. They weren't sure why time was important except that they said they wanted to make sure everything was fair. Even though data about all of the questions would be useful, Teresa thought that at this stage, looking for more than one type of data might be overwhelming for her children.

Teresa checked the terrain outside and realized that the shadows of most trees might get so long during the winter months that they would touch one of the buildings and become difficult to measure. That could be a learning experience but at the same time it would frustrate the children to have their investigation ruined after months of work. She decided to try to convince the children to use an artificial "tree" that was small enough to avoid our concern. To her surprise, there was no objection to substituting an artificial tree since, "If we measured that same tree every day, it would still be fair." She made a tree out of a dowel that was about 15 cm tall and the children insisted that they glue a triangle on the top to make it look more like a tree.

The class went outside as a group and chose a spot where the Sun shone without obstruction and took a measurement. Teresa was concerned that her students were not yet adept at using rulers and tape measures so she had the children measure the length of the shadow from the base of the tree to its tip with a piece of yarn and then glued that yarn onto a wall chart above the date when the measurement was taken. The children were delighted with this.

For the first week, teams of three went out and took daily measurements. By the end of the week, Teresa noted that the day-to-day differences were so small that perhaps they should consider taking a measurement once a week. This worked much better, as the chart was less "busy" but still showed any important changes that might happen.

As the weeks progressed, it became evident that the shadow was indeed getting longer each week. Teresa talked with the students about what would make a shadow get longer, and armed with flashlights, the children were able to make longer shadows of pencils by lowering the flashlight. The Sun must be getting lower too if this was the case, and this observation was added to the chart of questions. Later, Teresa wished that she had asked the children to keep individual science notebooks so that she could have been more aware of how each individual child was viewing the experiment.

The yarn chart showed the data clearly and the only question seemed to be, "How long will the shadow get?" Teresa revisited the Cheeks story and the children were able to point out that Cheeks's acorns were probably much closer to the tree than the winter shadows indicated. Teresa went on with another unit on fall changes and each week added another piece of yarn to the chart. She was relieved that she could carry on two science units at once and still capture the children's interest about the investigation each week after the measurement. After winter break, there was great excitement when the shadow began getting shorter. The shortening actually began at winter solstice around December 21 but the children were on break until after New Years. Now, the questions became "Will it keep getting shorter? For how long?" Winter passed and spring came and finally the end of the school year was approaching. Each week, the measurements were taken and each week a discussion was held on the meaning of the data. The chart was full of yarn strips and the pattern was obvious. The fall of last year had produced longer and longer shadow measurements until the New Year and then the shadows had begun to get shorter. "How short will they get?" and "Will they get down to nothing?" questions were added to the chart. During the last week of school, students talked about their conclusions and they were convinced that the Sun was lower and cast longer shadows during the fall to winter time and that after the new year, the Sun got higher in the sky and made the shadows shorter. They were also aware that the seasons were changing and that the higher Sun seemed to mean warmer weather and trees producing leaves. The students were ready to think about seasonal changes in the sky and relating them to seasonal cycles. At least Teresa thought they were.

On the final meeting day in June, she asked her students what they thought the shadows would look like next September. After a great deal of thinking, they agreed that since the shadows were getting so short, that by next September, they would be gone or so short that they would be hard to measure. Oh my! The idea of a cycle had escaped them, and no wonder, since it hadn't really been discussed. The obvious extrapolation of the chart would indicate that the trend of shorter shadows would continue. Teresa knew that she would not have a chance to continue the investigation next September but she might talk to the third-grade team and see if they would at least carry it on for a few weeks so that the children could see the repeat of the previous September data. Then the students might be ready to think more about seasonal changes and certainly their experience would be useful in the upper grades where seasons and the reasons for seasons would become a curricular issue. Despite these shortcomings, it was a marvelous experience and the children were given a great opportunity to design an investigation and collect data to answer their questions about the squirrel story at a level appropriate to their development. Teresa felt that the children had an opportunity to carry out a long-term investigation, gather data, and come up with conclusions along the way about Cheek's dilemma. She felt also that the standard had been partially met or at least was in progress. She would talk with the third-grade team about that.

Lore (pronounced Laurie), a veteran fifth-grade teacher

In September while working in the school, I had gone to Lore's fifth-grade class for advice. I read students the Cheeks story and asked them at which grade they thought it would be most appropriate. They agreed that it would most likely fly best at second grade. It seemed, with their advice, that Teresa's decision to use it there was a good one.

However, about a week after Teresa began to use the story, I received a note from Lore, telling me that her students were asking her all sorts of questions about shadows, the Sun, and the seasons and asking if I could help. Despite their insistence that the story belonged in the second grade, the fifth graders were intrigued enough by the story to begin asking questions about shadows. We now had two classes interested in Cheeks's dilemma but at two different developmental levels. The fifth graders were asking questions about daily shadows, direction of shadows, and seasonal shadows, and they were asking, "Why is this happening?" Lore wanted to use an inquiry approach to help them find answers to their questions but needed help. Even though the Cheeks story had opened the door to their curiosity, we agreed that perhaps a story about a pirate burying treasure in the same way Cheeks had buried acorns might be better suited to the fifth-grade interests in the future.

Lore looked at the NSES for her grade level and saw that they called for observing and describing the Sun's location and movements and studying natural objects in the sky and their patterns of movement. But the students' questions, we felt, should lead the investigations. Lore was intrigued by the 5E approach to inquiry (*engage, elaborate, explore, explain,* and *evaluate*) and because the students were already "engaged," she added the "elaborate" phase to find out what her students already knew. (The five Es will be defined in context as this vignette evolves.) So, Lore started her next class asking the students what they "knew" about the shadows that Cheeks used and what caused them. The students stated:

"Shadows are long in the morning, short at midday, and longer again in the afternoon."

"There is no shadow at noon because the Sun is directly overhead."

"Shadows are in the same place every day so we can tell time by them."

"Shadows are shorter in the summer than in the winter."

"You can put a stick in the ground and tell time by its shadow."

Just as Teresa had done, Lore changed these statements to questions, and they entered the "exploration" phase of the 5E inquiry method.

Luckily, Lore's room opened out onto a grassy area that was always open to the Sun. The students made boards that were 30 cm^2 and drilled holes in the middle and put a toothpick in the hole. They attached paper to the boards and drew shadow lines every half hour on the paper. They brought them in each afternoon and discussed their results. There were many discussions about whether or not it made a difference where they placed their boards from day to day.

They were gathering so much data that it was becoming cumbersome. One student suggested that they use overhead transparencies to record shadow data and then overlay them to see what kind of changes occurred. Everyone agreed that it was a great idea.

Lore introduced the class to the *Old Farmer's Almanac* and the tables of sunsets, sunrises, and lengths of days. This led to an exciting activity one day that involved math. Lore asked them to look at the sunrise time and sunset time on one given day and to calculate the length of the daytime Sun hours. Calculations went on for a good 10 minutes and Lore asked each group to demonstrate how they had calculated the time to the class. There must have been at least six different methods used and most of them came up with a common answer. The students were amazed that so many different methods could produce the same answer. They also agreed that several of the methods were more efficient than others and finally agreed that using a 24-hour clock method was the easiest. Lore was ecstatic that they had created so many methods and was convinced that their understanding of time was enhanced by this revelation.

This also showed that children are capable of metacognition—thinking about their thinking. Research tells us that elementary students are not astute at thinking about the way they reason but that they can learn to do so through practice and encouragement. Metacognition is important if students are to engage in inquiry. They need to understand how they process information and how they learn. In this particular instance, Lore had the children explain how they came to their solution for the length-of-day problem so that they could be more aware of how they went about solving the challenge. Students can also learn about their thinking processes from peers who are more likely to be at the same developmental level. Discussions in small groups or as an entire class can provide opportunities for the teacher to probe for more depth in student explanations. The teacher can ask the students who explain their technique to be more specific about how they used their thought processes: dead ends as well as successes. Students can also learn more about their metacognitive processes by writing in their notebooks about how they thought through their problem and found a solution. Talking about their thinking or explaining their methods of problem solving in writing can lead to a better understanding of how they can use reasoning skills better in future situations.

I should mention here that Lore went on to teach other units in science while the students continued to gather their data. She would come back to the unit periodically for a day or two so the children could process their findings. After a few months, the students were ready to get some help in finding a model that explained their data. Lore gave them globes and clay so that they could place their observers at their latitude on the globe. They used flashlights to replicate their findings. Since all globes are automatically tilted at a 23.5-degree angle, it raised the question as to why globes were made that way. It was time for the "explanation" part of the lesson and Lore helped them to see how the tilt of the Earth could help them make sense of their experiences with the shadows and the Sun's apparent motion in the sky.

The students made posters explaining how the seasons could be explained by the tilt of the Earth and the Earth's revolution around the Sun each year. They had "evaluated" their understanding and "extended" it beyond their experience. It was, Lore agreed, a very successful "6E" experience. It had included the engage, elaborate, explore, explain, and evaluate phases, and the added extend phase.

References

Konicek-Moran, R. 2008. *Everyday science mysteries*. Arlington, VA: NSTA Press.

Chapter 9

Seedlings in a Jar

Sara and Ina were having an argument. Well, maybe not an argument; more like a disagreement about a science topic. Ina and Sara wanted to be scientists when they grew up. They had watched a science video about how a plant gets most of the stuff that makes up its stems and leaves—what the scientists in the video called mass—from the air, as it grows. Sara wanted to know how this happened. She couldn't believe that air could hold anything that could build a plant.

She thought and thought about it, and the next day, she suggested to Ina that they try an experiment and grow a plant in a closed jar so that she could prove that plants didn't get their mass from the air.

"There isn't enough air in this big pickle jar to make leaves and stems for a whole plant so if they grow, we know that the stuff that makes the plant comes from the soil or the water."

"Well, I'm not even sure we can grow plants in a jar, and not even sure we can sprout seeds in a jar with so little air," said Ina.

"That's just the point," Sara said. "If they need air to make them get bigger, they won't grow in a jar. So if they *do* grow—which they won't, I'm sure!—we can prove I am right."

"Okay, but I want to have some control over this experiment because I don't think it will prove anything by just planting seeds in a closed jar," said Ina. "I want to weigh everything we use so we can tell if anything is missing when it is over." Ina had done scientific experiments before, and she knew about weighing ingredients and keeping track of them in her science notebook.

"Fair enough," said Sara. "It won't make any difference anyway so if you want to go to all of the trouble of weighing everything, be my guest. Anyway I'll bet the soil will weigh less, because *that* is where the plant gets its mass."

So they did weigh the jar and cover, the soil they put in, the water they added and, of course, the seeds they planted in the soil. Ina kept accurate records in her science notebook about everything they did. She even recorded the weight of the whole thing after it was put together and sealed up.

Several weeks went by. The covered jar got very misty inside and, to their surprise, the seeds germinated and the seedlings grew up almost to the top of the jar.

"There, you see!" said Sara. "The jar was closed as tight as can be, so no air leaked in or out and the plants grew just fine. The mass must have come from the soil or the water."

"Not so fast," said Ina. "We have some weighing to do."

"What in the world for?" asked Sara. "We just proved that air had nothing to do with the seeds sprouting or the plants growing, didn't we?"

"Not to me we didn't," said Ina. "I want to weigh everything again."

"Suit yourself, Ina," said Sara. "It's a waste of time. It will weigh less because the soil and water got used up."

Sara and Ina weighed the whole set up and both said, "OMG!"

Neither girl could believe their eyes. "Weigh it again," said Sara. 'There has to be something wrong!"

Ina weighed the whole thing and got the same answer. Now neither girl knew what had happened.

"Let's weigh everything separately and see what it adds up to," said Sara.

They did and it all added up to the same number. They weighed the soil, which was wet with moisture, the jar, the lid, and the plants, which by now were quite large.

"Okay, now what?" said Sara.

"I think we really need to do this again," said Ina.

Purpose

This story really leaves us hanging! It's a great one for real investigation! There are two purposes of the story: The first is to investigate closed systems. Anything that happens inside uses up only the materials in the jar, because there is no access to the outside world. The second purpose is for students to understand that air has mass and contains the materials that plants need to make their food and build their structure. I think a further purpose of the story is to allow the students to be puzzled by the outcome, and learn from this puzzlement how to try to find out how things happen.

Related Concepts

- Systems
- Photosynthesis
- Contents of the atmosphere
- Closed systems
- Germination
- Experimental design

Don't Be Surprised

Your students will probably be very surprised at the outcome of their investigation. It would seem logical that the system would gain weight since the plants are growing inside the jar and they must weigh something! They are probably not aware of at least two things that are important, the implications of a closed system and the concept of air as having mass.

Content Background

This story is about systems more than it is about seeds and plant growth, but you will want some information about the latter, so I will provide that in this section. But first, let us look at the concept of systems.

A *system* is a set of individual entities that interact and influence each other in the performance of a given task. The entities can be objects, people, internal organs, buses, plants, or dozens of other things that somehow interact in a meaningful way. The American Association for the Advancement of Science (AAAS 1993) believes the idea of systems to be one of the most important overarching concepts in learning and strongly urges educators to make the concept of systems a central part of all subjects taught in schools. After all, we are surrounded by systems, we live within systems and anything we teach or study is encased somehow in some system, somewhere.

Students can apply the idea of systems to any topic and, most importantly, could see the relationships among the various topics they study. We so often complain that students do not see the big picture, but instead learn things in isolated units and then fail to apply them across the curriculum. If systems were used as a unifying theme across all subjects, I believe that there would be more complete understanding of how everything in our everyday lives is related. In other words, they would see how the ideas involved in a transportation or political system related to how things work in an ecosystem or even a digestive system. Any change in any system affects everything else in that system.

Systems are said to be *closed* or *open*. Actually there is a third type, an *isolated* system, but it has little importance here. A *closed system* such as the one in the story can *exchange energy but not matter*. The matter that is in the jar remains constant and cannot interact with the outside environment. However, sunlight can get through the glass and provide energy for photosynthesis. A hot liquid in a container, like coffee in a thermos, is another example of a closed system. Thermal energy can pass through the container walls so that eventually the hot liquid reaches equilibrium with its environment, but the coffee sealed inside can neither take in nor give out any of its substance.

An *open system* allows both matter and energy to be exchanged with the environment. Our Earth is an example of an open system, where everything can react with everything else. Matter and energy are being exchanged all of the time. If the jar in the story had not been sealed off, it would have been classified as an open system since it could exchange matter and energy with anything outside the jar.

With the idea of the seeds germinating and growing in what Sara considered an impossible growing environment, we add a different content twist to the concept of a closed system. Sara was under the influence of the popular misconception that air has no mass and therefore cannot possibly be part of the materials involved in the production of the plant tissues, or the *mass*, of growing plants. She believed that the plant mass comes from the soil and water, through the roots. She also believed that there was not enough air in the jar to grow anything.

In the 1600s Jan Baptista Van Helmont planted a willow sapling in 200 pounds of soil, which after five years gained 164 pounds. (Obviously, he kept track of weights in his science notebook!). The soil lost only 57 grams of soil (2 ounces) during that time. Realizing that the loss in soil mass could not be responsible for the gigantic change in mass, he assumed it was the rainwater he had added that made up the difference in mass. Although he was aware of the carbon dioxide in the atmosphere, he could not believe that it could be responsible for the 164 pounds of additional weight. Here is an example of a misconception held by a scientist who did not have enough information to reach a conclusion that we now know is acceptable. This conclusion is that the carbon from the carbon dioxide in the air and water obtained through the roots can provide enough mass through photosynthesis to account for the gain in mass of the plants that grow on this Earth. The carbon and hydrogen in the presence of solar energy and chlorophyll are used to make sugars, which bond together to make starch and finally cellulose to form the cell walls of the cells from which plant tissues are made. By-products are newly formed water and oxygen, which are released into the atmosphere. Thus, the girls noticed the droplets of water on the jar's inside surface, which showed that the water had condensed on the glass. There was enough carbon dioxide in the jar to provide the carbon necessary to allow plant growth. Since this was a closed system, mass was conserved since the only material available to the seed and subsequent plants was contained in the jar and the system should not gain any weight even though the appearance inside the jar changed considerably. Since the jar was transparent, solar energy could enter the system from the outside. Excess heat, if there was any could also be released through the glass and so energy could be exchanged. This permits us to use our definition of a closed system very well. The chemical formula that includes the formation of the new water molecules is 6 CO_2 + 12 H_2O + energy and chlorophyll $\rightarrow$ $C_6H_{12}O_6$ + 6 O_2 + 6 H_2O

Seeds need warmth and moisture in order to germinate. A few seeds, such as lettuce seeds also need light to activate the processes involved in germination. Some maple seeds can only last for a few weeks before they die if they do not germinate. Other seeds, such as the Lotus can remain viable for thousands of years. But it is the water and warmth that allow the seed to germinate. Water enters the seed, softens the seed coat and allows the chemical processes necessary for germination to proceed. Gibberellic acid is released and begins a series of rather complicated chemical and genetic steps that result in a dormant seed becoming a full-fledged plant. This plant is capable of producing more seeds so that the life cycle is completed. In the jar in the story, the girls provided the water and the growth medium, the soil. The room temperature and the Sun provided the warmth and that is all the seeds needed to germinate. The sunlight penetrating the glass jar walls provided the energy to cause the germinated seeds to grow into seedlings and then plants. As you may notice from the formula for photosynthesis, oxygen and water are also produced in the process and continue to provide necessary elements for plant growth. Plants need oxygen in order to respire (break down nutrients to produce useful energy) and water. The jar is a little microcosm of the outside world and might continue to exist for some time barring some changes inside that might inhibit the processes and stop the cycle. In the open system of the outside world, pests, disease, climate change, and a host of other problems may affect plants in the ecosystem. Yet, the open system of our Earth has survived for millions of years, changing in ways that have kept succession alive. We are now facing the prospects of what we humans have done to the ecosystem at large that may have dire consequences for living things on the planet.

Related Ideas From the National Science Education Standards (NRC 1996)

K–12: Unifying Concepts and Processes—Systems

- The natural and designed world is now too large and complex to comprehend all at once. Scientists define small portions for the convenience of investigation. These portions are referred to as *systems.*

- A system is an organized group of related objects or components that form a whole. Systems have boundaries, components, resources, flow (input and output), and feedback.
- Within systems, interactions between components occur.
- Systems at different levels of organization can manifest different properties and functions.
- Thinking in terms of simple systems encompasses subsystems as well as identifying the structure and function of systems, feedback and equilibrium and identifying the distinction between open and closed systems.
- Understanding the regularities in systems can develop understanding of basic laws, theories, and models that explain the world.

K–4: The Characteristics of Organisms

- Organisms have basic needs. For example animals need air, water, and food; plants require air, water, nutrients and light. Organisms can survive only in environments in which their needs can be met.
- The world has many different environments and distinct environments support the life of different types of organisms.
- Each plant or animal has different structures that serve different functions in growth, survival, and reproduction.

K–4: Life Cycles of Organisms

- Plants and animals have life cycles that include being born, developing into adults, reproducing, and eventually dying. The details of this life cycle are different for different organisms.
- Plants and animals closely resemble their parents.

5–8: Structure and Function in Living Systems

- Living systems at all levels of organization demonstrate the complementary nature of structure and function. Important levels of organization for structure and function include cells, organs, tissues, organ systems, whole organisms, and ecosystems.

5–8: Reproduction and Heredity

- Reproduction is a characteristic of all living systems because no individual organism lives forever. Reproduction is essential to the continuation of every species. Some organisms reproduce asexually. Other organisms reproduce sexually.

5–8: Diversity and Adaptations of Organisms

- Millions of species of animals, plants, and microorganisms are alive today. Although different species might look dissimilar, the unit, among organisms becomes apparent from an analysis of internal structures, the similarity of their chemical processes and the evidence of common ancestry.

Related Ideas From Benchmarks for Science Literacy (AAAS 1993)

K–2: Systems

- Most things are made of parts.
- Something may not work if some of the parts are missing.
- When parts are put together, they can do things that they couldn't do by themselves.

3–5: Systems

- In something that consists of many parts, the parts usually influence one another.

6–8: Systems

- A system can include processes as well as things.
- Thinking about things as systems means looking for how every part relates to others. The output from one part of a system (which can include material energy or information) can become the input to other parts. Such feedback can serve to control what goes on in the system as a whole.
- Any system is usually connected to other systems, both internally and externally. Thus a system may be thought of as containing subsystems and as being a subsystem of a larger system.
- Some portion of the output of a system may be fed back to the system's input.
- Systems are defined by placing boundaries around collections of interrelated things to make them easier to study. Regardless of where the boundaries are placed, a system still interacts with its surrounding environment. Therefore, when studying a system, it is important to keep track of what enters or leaves the system.

K–2: Diversity of Life

- Some animals and plants are alike in the way they look and in the things they do, and others are very different from one another.
- Plants and animals have features that help them live in different environments.

K–2: The Structure of Matter

- Things can be done to materials to change some of their properties, but not all materials respond the same way to what is done to them.

3–5: Diversity of Life

- A great variety of kinds of living things can be sorted into groups in many ways using various features to decide which things belong in which group.

- Features used for grouping depend on the purpose of the grouping.

6–8: Diversity of Life

- Animals and plants have a great variety of body plans and internal structures that contribute to their being able to make or find food and reproduce.
- For sexually reproducing organisms, a species comprises all organisms that can mate with one another to produce fertile offspring.

Using the Story With Grades K–4

Young children can examine their toys and things that they build or use to identify the parts that make up what we call systems. According to the standards, they should realize that toys are made of parts and that if some parts are missing, the toy does not work correctly. This can be an important introduction to the concept of systems. A bicycle cannot operate without a wheel and an electronic toy cannot operate without a source of power such as batteries or a wind-up spring. Looking at toys and identifying their parts can also be instructive for children as they develop the idea of systems. It is important that young children begin their understanding of systems by realizing that the parts of systems interact with each other in ways that make the system work properly.

When I was a young boy, I became enamored with locks and to my parents' chagrin I managed to take apart most of the locks on the doors of our house. It seemed like I always had parts left over when I reassembled them. Of course they didn't work and we had to start all over again. But in doing so, I learned more about how locks work than I would have in any other way. I wanted to believe that it made no difference if one little part was left out of the lock system. But, of course, it did. Helping children to see that successful systems have to consist of all of their parts is one of the most important things they can learn. The application of this idea to the larger examples of systems in the world will prove invaluable.

You might try giving the probe "Is it a system?" from *Uncovering Student Ideas in Science, Volume 4* (Keeley and Tugel 2009). This probe will provide you with more information about your students' knowledge about systems. Students are asked to choose from a list, those things that they think are systems, and then explain their reasoning. In all of these activities, the important thing is the discussion that follows. A teacher learns more about how and what their students learn by listening than by talking. You may hear students holding opposite points of view and not even realizing it. With careful probing you can help them to see what they are saying is in conflict. I once had a student who was in the middle of an explanation and stopped and said, "now that *I heard what I just said,* I can see that I am heading in the wrong direction." Hearing oneself speak out loud is often a better key to understanding what we are thinking than just pondering it silently. Additionally, writing it or drawing it can also add information that aids in understanding, especially, if one is writing for oneself as the audience. The writer can be more honest that way.

Your students may want to try the activity in the story. Young children may not be ready to use the skills necessary to carry out the activity. Older elementary students who can use a balance or scale and follow the story line carefully can repeat the activity and after predicting the outcome, can find the seemingly amazing outcome for themselves. They may want to see how long the microcosm in the jar will perpetuate itself. If you help them to use plants that will not grow too tall too quickly, the chances are that it might go on for some time.

Using the Story With Grades 5–8

Middle school children will be just as surprised as the younger students with the results and you might be too. Don't be surprised if you expected the jar of plants to weigh more. It almost seems counterintuitive that the plants could grow from the seeds and still not add any weight to the system. This particular system however, is the secret to the result. Try to focus on the system being closed and appeal to their knowledge that nothing in and nothing out yields no changes.

The inspiration for the story came from the probe, "Seedlings in a Jar," in Keeley and Tugel's book (2009). Although giving this probe may seem redundant since it follows the story so closely, it could be used as a summative assessment. You would need to pay closer attention to the part of the probe where the students are required to elucidate in their own words why the system did not gain weight.

When the students decide to replicate the story, you may want to talk with them about systems and have them find as many different kinds of systems that they can think of in their collective experiences. This particular moment in the process is the best time to introduce the vocabulary since the words will be in context. Older students, being more facile with balances, will want to weigh the substances before and after, and check the results several times. I have found that their disbelief based on prior conceptions, is strong and sometimes hard to shake. Prior conceptions held for a long time are difficult to change with one activity no matter how strong the evidence may seem to us. If you do not get all of your students to understand the concepts involved here, do not be discouraged. Instead, congratulate yourself on having built one more plank in the scaffolding that leads to final understanding. Believing that the air in the jar was sufficient to contain the building blocks of the plant tissue is completely ridiculous to students who believe that air has no mass. If you are planning to follow up this story with photosynthesis, I believe that you will find the students more receptive to the ideas involved because they have actually seen results that point to the carbon dioxide in the air as the source of carbon that will be the backbone of the starch and sugar molecules and eventually the cellulose.

If you would like to see an interview of a young student by an interviewer who uncovers his lack of understanding about photosynthesis, log onto the following: *www.learner.org/resources/series26.html* and watch the video "Lessons From Thin

Air." It will give you an idea how difficult it is to change student conceptions about air and mass.

Related Books and NSTA Journal Articles

Keeley, P. 2005. *Science curriculum topic study: Bridging the gap between standards and practice.* Thousand Oaks, CA: Corwin Press.

Keeley, P., F. Eberle, and C. Dorsey. 2008. *Uncovering student ideas in science, volume 3: Another 25 formative assessment probes*. Arlington, VA: NSTA Press.

Keeley, P., F. Eberle, and L. Farrin. 2005. *Uncovering student ideas in science, volume 1: 25 formative assessment probes*. Arlington, VA: NSTA Press.

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Keeley, P., and J. Tugel. 2009. *Uncovering student ideas in science, volume 4: 25 new formative assessment probes*. Arlington, VA: NSTA Press.

Konicek-Moran, R. 2008. *Everyday Science Mysteries: Stories for inquiry-based science teaching*. Arlington, VA: NSTA Press.

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Konicek-Moran, R. 2010. *Even More Everyday Science Mysteries: Stories for inquiry-based science teaching*. Arlington, VA: NSTA Press.

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Annenberg Media. 2009. Lessons from thin air. Minds of Our Own. *www.learner.org/resources/series26.html*

Keeley, P., and J. Tugel. 2009. *Uncovering student ideas in science: 25 formative assessment probes, Volume 4.* Arlington, VA: NSTA Press.

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Grades K–8

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