EVERYDAY PHYSICAL SCIENCE MYSTERIES

STORIES FOR INQUIRY-BASED SCIENCE TEACHING

Richard Konicek-Moran

NSTA press
National Science Teachers Association

Everyday Physical Science Mysteries

Stories for Inquiry-Based Science Teaching

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The Stories and Background Materials for Teachers

acknowledgments

I would also like to dedicate these stories and materials to the dedicated and talented teachers in the Springfield Public Schools in Springfield, Massachusetts. They have been my inspiration to produce materials that work with city as well as rural children.

I would like to thank the following teachers, educators, and administrators who have helped me by field-testing the stories and ideas contained in this book over many years. These dedicated educators have helped me with their encouragement and constructive criticism:

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Third-grade team at Burgess Elementary in Sturbridge, Massachusetts

Second-grade team Burgess Elementary in Sturbridge, Massachusetts

Fifth-grade team at Burgess Elementary in Sturbridge, Massachusetts

Teachers at Millbury, Massachusetts, Elementary Schools

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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

Ask elementary or middle school teachers which of the disciplines they are most afraid to teach and they will likely answer, "The physical sciences." Now with the new Standards, we get to add engineering and math to the list of possible responses. These too probably seem scary, but this need not be the case. When these subjects are taught conceptually and in everyday settings, teachers soon see that they, and their students, can tackle the topics without trepidation.

The positive thing about physical science and engineering activities is that they offer immediate feedback to the people doing the activity. In biology and Earth sciences, one might have to wait weeks or months for an activity to provide a result. In most physical science activities or investigations, the result takes only a minute or two, and students can either formulate a conclusion or do the activity over again.

As for math, the activities generated by these stories provide data that has meaning for the experimenter. Unlike the young student who told me "Math is pages and pages of other people's problems," the math involved in *Everyday Science Mysteries* provides immediate and relevant data. Students are doing calculations on numbers that have personal meaning to them, data they have collected. It is less a chore and more a means to answers that lie within the scope of their interest.

Your students will be asked to engage in engineering tasks that come about as a natural response to the stories—for instance to apply their knowledge about sound to improve a tin can telephone. Through helping to solve the mysteries the children in the stories encounter, your students get to invent a way to mark or keep time or apply their knowledge of pendulums to solve a crooked swing problem, just to name a few.

In this book, you will find enough background material and resources to give you the strength and courage to engage your students in inquiry into physical science concepts. And for additional comfort, there are now available many resources to help those who feel lacking in physics, math, or engineering.

These stories are packaged in separate subject matter volumes so those who teach only one of the three 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 around 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 around 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 Day. 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 (Metz 1995) 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.

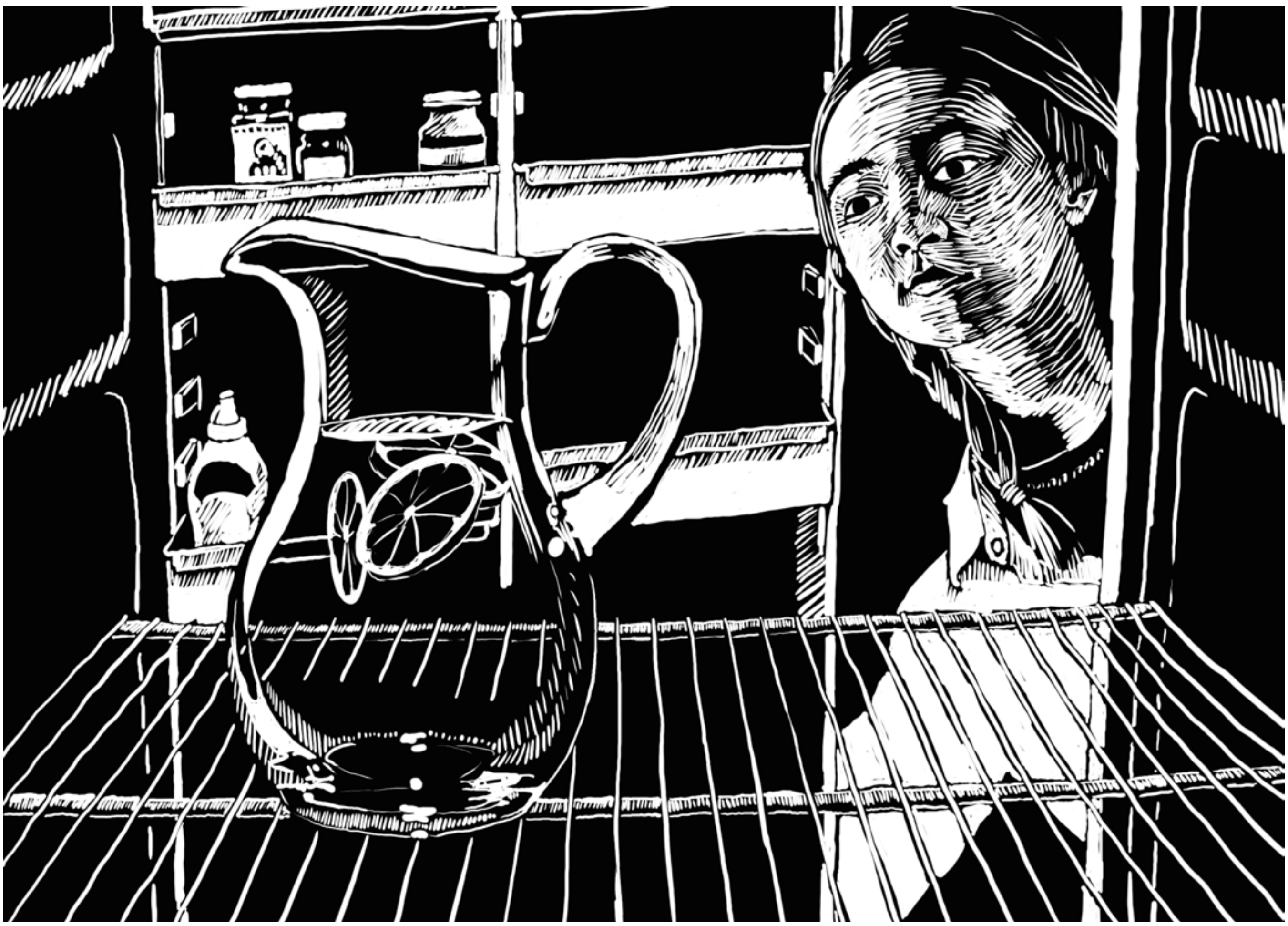
The students made posters explaining how the seasons could be explained by the tilt of the Earth and the Earth's revolution around the Sun each year. They had "evaluated" their understanding and "extended" it beyond their experience. It was, Lore agreed, a very successful "6E" experience. It had included 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 12

How Cold Is Cold?



Kristin filled her glass with ice cubes from the freezer, all the way up to the top. She then filled the glass with lemonade and sat down to drink it. The day was hot and muggy and Kristin did not take long to finish her drink. When she was finished she dumped almost a full glass of ice cubes into the sink.

Kristin's father had been watching the entire scene. "You know, Krissy," he said, "you don't have to waste all of that ice. Why do you put so much ice into your glass?"

"I like my lemonade really cold," she responded, "and the more ice I put in, the colder the lemonade gets."

"Are you sure about that?" asked her dad.

"Of course," answered Kristin. "It makes sense. More cold ice makes a cold drink, well … colder."

"Maybe," said her dad "more ice might make it cool down faster, but would it really make it colder? Look! You threw away almost all of the ice!"

"It was cold enough, so I drank it all down. I can't help it if all of the ice didn't melt. Besides, if I let all of the ice melt, the lemonade would have gotten colder and colder and maybe too cold to drink. There was a lot of cold in the ice that had to go into the drink and the more ice, the more cold there was to cool the drink."

"I don't know," mumbled her dad. "Something doesn't quite make sense here. Could the lemonade get colder than the ice that's in it?"

"Well, I think so," Kristin replied cautiously. "Or maybe not. I don't really know. More ice would keep on making it colder as long as there was still ice, wouldn't it?"

"We need to do some experimenting," said her dad. "We need a hypothesis or two. It looks like we have a least a couple of questions here."

Purpose

Heat and cold are often difficult concepts for children to understand. First, our everyday sloppy language gives them a predisposition to such common misconceptions as cold being a substance that moves from place to place. How often have we told others to "Close the door, you're letting the cold in?" Our colloquial language often reinforces the existence of "cold energy," when it is scientifically acceptable to refer only to heat as a form of energy that is transferred from a warmer object to a cooler one and that cold is an absence of heat.

Secondly, the story tries to set the stage for discussions and inquiry into the nature of temperature and heat and to the fact that heat exchange is the cause of what scientists call a *phase* change—when something goes from liquid to solid or vice versa. In essence this may be the students' first encounter with the laws of thermodynamics.

This story actually has its origin in a personal event that happened to my family while we were living in Africa. Our highly prized and ancient refrigerator labored daily against the oppressive 43°C degree temperature and did so valiantly just to maintain an internal temperature low enough to preserve our food. Making ice in the refrigerator was a luxury and we used it sparingly, all except our teenage daughter who is personified as Kristin in the story. Her insistence on using large quantities of ice for her drinks led to many confrontations between Kristin and me, which are literally very close to the dialog in the story.

Related Concepts

- Energy
- Temperature
- Thermal energy
- Cooling
- Solid
- Phase change
- Energy transfer
- Heat
- Melting
- Freezing
- Liquid
- Physical change

Don't Be Surprised

Your students may well believe that cold is something that moves from colder places into warmer places and cools them off. Air conditioners blowing out cold air may add to this idea. They may believe that cold is an entity that moves much like a wind or an object. Who can blame them when we use language that emphasizes that belief? It would follow that they would believe that more ice would add to the transfer of more cold into the lemonade. Kristin thought that the more ice there was in the glass, the colder the drink would become for that very reason. They will be surprised when they find out that once a drink with ice cubes reaches a certain temperature, the continued presence of ice in the drink will not lower the temperature further.

Content Background

If you have ever filled your glass with ice to cool your drink, you will have noticed that the drink never got "too cold to drink!" Even if you forgot your drink only to return later and find the ice almost gone, you will have noticed that it is still drinkable, temperature-wise. It might certainly have been diluted and watery due to the melting of the ice, but the temperature was still within the comfort zone for drinking. How can this be when we think: There was a lot of cold in the ice that had to go into the drink and the more ice, the more cold there was to cool the drink. Should it not have gone on giving its cold to the drink, making it colder and colder?

Could it be that instead of the cold going into the drink, the heat from the drink might be going into the ice? Is this what makes ice melt? If the drink were very warm, would the ice melt faster? These wonderings can be made into testable questions and might lead you as the teacher to try out some ice experiments yourself before working with the children. Before using this story with the children I recommend that you obtain a copy of *Science Matters* by Hazen and Trefil and read Chapter 2 on energy. Their explanation of energy, in this case heat energy, will benefit you greatly and give you the confidence you need to lead your students through their inquiries. Basically here it is in a nutshell:

Thermal energy, temperature, and heat are entirely different things to a physicist. *Thermal energy* is the total amount of kinetic energy in a substance. The amount of thermal energy in a substance is determined by the amount of kinetic energy created by the amount of bouncing around of all of the molecules that make up the substance. A thermometer can only measure the thermal energy of the molecules that bounce off it and certainly not all of the molecules in a substance, but you can assume that the thermometer would register the same if it is placed anywhere in the container of the substance you are measuring.

Temperature is a human-devised concept that measures the difference in this thermal energy among various objects on arbitrary temperature scales such as Fahrenheit, Celsius, or Kelvin scales. It tells us the average amount of thermal energy in any substance.

Heat is usually defined as the transfer of energy from an object that is hot to one that is cooler.

Every substance has some thermal energy in it unless it has somehow miraculously reached the temperature of absolute zero, a temperature impossible to attain even in a laboratory. Absolute zero is theoretically reached when no more thermal energy can be extracted from a substance. The larger the substance, the more thermal energy is present. Two ice cubes have twice the thermal energy as one ice cube! You might be very willing to have a small droplet of boiling water placed on your hand but not a pot of boiling water. Why not? Because there is much more heat in the pot of water than in the droplet despite the fact that they are the same temperature! Here lies the difference between heat and temperature. These ideas may seem counterintuitive to many of you, but don't let that scare you away from physics. Instead, let it intrigue you and entice you to learn more.

Thermal energy is attributed to the motion of molecules in any substance. More molecular activity means greater thermal energy and less activity means less. So, when you heat or cool something, you are changing the activity level of its particles. Remember, heat is referred to as the energy that can be transferred from one substance to another. By adding energy to any substance, the amount of thermal energy it contains can be increased, by transferring it from the donor, such as the Sun, electricity, burner, or nearby higher energy source to the receiver. Heat energy can be transferred from the warmer to the cooler by one of three methods, by conduction, radiation, or convection. You have felt the result of *conduction* when you put a spoon into a hot cup of liquid and then touched the spoon. The heat energy is transferred directly from the collision of the atoms in the liquid to the atoms in the spoon to you. You may also have felt the transfer of energy by *radiation* if you stood close to a fire or an electric heater or lamp. The energy of the heat source is in the form of infrared energy (a high energy part of the light spectrum), which in turn excites your heat sensors and you feel heat. In *convection*, the atoms in a liquid or gas set up a current of rising and falling atoms, which eventually bring everything in the substance to the same temperature. It all boils down to the laws of thermodynamics and in this case, the second law. We can summarize the second law of thermodynamics by saying that heat energy moves spontaneously from a warmer area to a cooler area. An interesting phenomenon about conduction is that some substances conduct heat better than others. For instance, if you touch metal, it feels cooler than other substances in a room. This is because the heat from your body transfers more quickly to the metal and it feels cooler to you. If the metal has been in the room for a long time, it will have the same temperature as the rest of the objects in the room. Your body will be fooled into thinking that the metal is cooler when it is really not.

Kristin has formed a common misconception about energy that includes cold as a form of energy that can move from one place to another. Secondly, she has reckoned that there is an unlimited supply of this “cold” in the ice that can continue to move into the drink and continue to drop the temperature until the ice is gone. In her mind, the “cold” in the ice disappears into the drink until it is all used up. If this were true, it would be entirely possible for the drink to become colder than the temperature of the ice itself. We know this to be untrue from experience. The heat in the drink will transfer into the ice causing it to melt. The drink will never get any colder than the temperature of the ice in it. Since the ice and the drink will become the same temperature and heat can only flow from warmer to cooler there will be no heat transfer. Only if the liquid in the drink warms to a temperature higher than the ice will heat continue to flow. In other words, heat can flow from one substance to another if there is a temperature difference between the two.

This can be tested with the aid of a thermometer and a glass of ice water. The heat in the drink changes the phase of the ice from solid to liquid by increasing the energy in the atoms in the ice as it melts. Mind you, the temperature of the ice cubes will not change as long as the cubes remain in solid form, but the heat energy from the drink will eventually change the state of water from solid (ice) to liquid. And, the resulting temperature of the ice drink will never go below that of the temperature of any given ice cube in the drink. The amount of heat in the drink, transferred to the cubes will eventually result in temperature equilibrium between the ice and the drink. When equilibrium has been reached, the temperature will go no lower. In essence, when the ice and drink have reached the same temperature, there can be no further flow of energy since everything is the same temperature. Otherwise, the law of thermodynamics that states that heat flows from the warmer substance to the cooler substance would be broken (or at least repealed!). So far, that has never happened. And I anticipate that in your work with the students, the law will be upheld.

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

K–4: Properties of Objects and Materials

- Materials can exist in different states—solid, liquid, and gas. Some common materials such as water, can be changed from one state to another by heating or cooling.

K–4: Light, Heat, Electricity, and Magnetism

- Heat can be produced in many ways such as burning, rubbing, or mixing one substance with another. Heat can move from one object to another.

5–8: Transfer of Energy

- Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclear energy, and the nature of a chemical change. Energy is transferred in many ways.
- Heat moves in predictable ways, flowing from warmer objects to cooler ones until both reach the same temperature.

Related Ideas From Benchmarks for Science Literacy (AAAS 1993)

K–2: The Structure of Matter

- Heating and cooling cause changes in the properties of materials. Many kinds of changes occur faster under hotter conditions.

3–5: Energy Transformations

- When warmer things are put with cooler ones, the warm ones lose heat and the cool ones gain it until they are all the same temperature. A warmer object can warm a cooler one by contact or at a distance.

6–8: Energy Transformations

- Heat can be transferred through materials by the collision of atoms or across space by radiation. If the material is fluid, currents will be set up in it that aid the transfer of heat.
- Energy appears in different forms. Heat energy is in the disorderly motion of molecules.

Using the Story With Grades K–4

This story can be used with the K–4 grades quite easily since Kristin's age is not clearly evident from the reading. As seen in the Standards and Benchmarks, the expectations for K–4 are that students will be able to distinguish between things that are warm and cold and to realize that when warm things are placed next to cool things, the cool things become warmer and the warm things become cooler. Also implicit in the expectations is the fact that substances can change from one state to another.

Actually, the story works better with third or fourth graders than with younger students although the discussion of the situation can give you a good insight into your students' thoughts about heat and the transfer of heat at any level. Most children by the time they come to school have had experience with ice and freezing and melting. They have also had time to develop incomplete conceptions about what is happening in this process. It might be best to focus on the melting of the ice cube for younger children and see what they already know about the phenomenon. An ice cube-melting race is a good way to involve the children and to see what they know about the process. Give each child an ice cube in a small dish and ask them to do what they can to make it melt as quickly as possible. They cannot touch it with any part of their bodies or take it to any other part of the room but are free to do anything else. Some will blow on the cube and others will wave their hands over the cube while others may move it back and forth with a pencil or pen. While you move about the room, you can ask them why they are doing what they are doing.

You may also want to administer one of probes on melting from *Uncovering Student Ideas in Science,* volumes 1 or 2 (Keeley, Eberle, and Farrin 2005; Keeley, Eberle, and Tugel 2007). "Ice Cubes in a Bag" is in volume 1 and "Ice Cold Lemonade" is in volume 2. Young children are not adept at reading thermometers and this limits their ability to conduct temperature studies. You can of course demonstrate and read the thermometer for them but this is secondhand science. It is a wonderful opportunity to teach them about temperature changes, and there are digital thermometers that can be used for this purpose. Don't pass up the opportunity to have a class discussion about the story so that you can become aware of your students' ideas about heat and freezing and melting.

For the third and fourth graders the story should make sense and if they are able to use thermometers, the questions raised by Kristin and her dad can be tested. The students should discover that the temperature reaches equilibrium as soon as the liquid and the ice in the glass are at the same temperature. After this point, no matter how much ice is left in the glass, the temperature will remain the same since the flow of energy from warm to cool cannot take place since there is no difference. There will however, be a constant flow of energy from the liquid to the ice since the energy from the room will affect the liquid and the ice will absorb the excess heat as needed to maintain the equilibrium. After the ice all melts, the liquid will gradually move in the direction of the room temperature and the students will notice that the temperature will rise as it does so. Their explanations of these phenomena will provide an enlightening conversation for you and for the students. Be sure to bring the room temperature to the attention of the students by asking them how high they think the drink temperature will go. All of these findings should be put into their science notebooks and the conclusions and explanations as well. Your students might want to finish the story in their books now as well. If you need a prompt, you might ask them to predict what Kristin will say to her dad after she has experimented as they have done, backing up her response by using their findings.

Using the Story With Grades 5–8

Middle school students should have skills in reading thermometers but do not expect them truly to understand the difference between temperature as read on the thermometer and the concept of heat, which is a complete abstraction. This is because in everyday life, we measure differences in energy by temperature even though energy is much different. Students therefore often confound the two. In fact the Standards documents suggest that at this age the time and effort spent in trying to teach students the difference is not worth it. Overall, the most important lesson to be learned here is that the energy moves from a higher energy source to a lower energy source, and it is the heat that is transferred and not the "cold." I would also add here that it is important to realize that it takes energy to change a solid to a liquid and a liquid to a gas and that energy does not necessarily change the temperature of the substances involved. To wit, adding heat to boiling water, once it is at a full boil, does not raise the temperature of the water. It will remain at 100°C at sea level. The added energy goes into continuing the phase change from liquid to gas and will continue to do so until the liquid is entirely evaporated.

I suggest using the story with grades 5–8 as a stimulus for discussion and then for the design of experiments to find out the answer to Kristin's dilemma. The discussion will probably produce ideas that can be placed on the "our best thinking" chart and can be changed to questions and eventually hypotheses. The role of the teacher is to help focus the students' thinking on designing experiments that will answer their questions or support or not support their hypotheses.

For example, students may suggest putting thermometers in several glasses of water and then add varying amounts of ice to each one so they can monitor the temperature changes they anticipate as the ice melts. Should the containers all be made of the same material? Should the ice cubes be as much the same size as possible? Should the ice cubes come from the same tray? How should data be recorded? Will they graph them? When is the experiment over; when the ice is completely melted in all, some, one? The design depends, of course, on the hypothesis and the students should be helped to make the tests as fair as possible. Once the data are in, there may be small discrepancies. Small differences may be tempting for students to make their point. Your role might be to ask, how much difference in a measurement is significant? For example, suppose a student puts five ice cubes in one glass and one in another, and hypothesizes that the glass with five cubes will result in a lower temperature. The thermometer in the five-cube glass registers one degree cooler than the one-cube glass. One would expect if there were to be a difference, it would be more than one degree. Where could the difference come from? Perhaps the reading was faulty or perhaps the thermometers are not synchronized or perhaps the timing of the reading was different. Redoing the experiment as a class demonstration with all possibilities covered would be a reasonable solution to that problem. Remember, the stories and this book are about inquiry. There is not always a clear path to discovery and understanding. Having the students talk it all out will reap huge rewards. Then again, there may not be total agreement from all students. This is part of science too. Read the article "Teaching for Conceptual Change," by Watson and Konicek (1991) to see how one teacher handled situations like this. During the discussion, always ask the student who makes a conclusion statement to verify the statement with evidence. Science goes deeper than opinions and your role is to remind the students of this fact. You may possess one of the computer-assisted probes that will measure the temperatures accurately and even graph the changes on the computer screen as they occur. I do not discourage the use of these but ask you to consider how your students might benefit from collecting data and doing their own graphing. Following this, the probe apparatus might solidify the concept and the students could say that the apparatus "agreed with their findings." See the subtle difference there?

I sincerely believe that at the end of the experiments and discussion, your students and perhaps, even you, will have a new and clearer idea about energy transfer and about the process in which knowledge is gained.

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