A critical approach to teaching science is concerned less with students accumulating undigested facts and scientific definitions and procedures, than with students learning to think scientifically. As students learn to think scientifically, they inevitably organize and internalize facts, learn terminology, and use scientific procedures. But they learn them deeply, because they are tied into ideas that they have thought through, and hence do not have to "re-learn" them again and again.

The biggest obstacle to science education is students' previous misconceptions. Although there are well-developed, defensible methods for settling many scientific questions, educators should recognize that students have developed their own ideas about the physical world. Merely presenting established methods to students does not usually affect their inner beliefs; they continue to exist in an unarticulated and therefore unchallenged form. Rather than transferring the knowledge they learn in school to new settings, students continue to use their pre-existing frameworks of belief. Students' own emerging egocentric conceptions about events in their immediate experience seem much more real and true to them than what they have superficially picked up in school.

For example, in one study, few college physics students could correctly answer the question, "What happens to a piece of paper thrown out of a moving car's window?" They reverted to a naive version of physics inconsistent with what they learned in school; they used Aristotelian rather than Newtonian physics. The *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* offers another example. A student was presented with evidence about current flow that was incompatible with his articulated beliefs. In response to the instructor's demonstration, the student replied, "Maybe that's the case here, but if you come home with me you'll see it's different there." This student's response graphically illustrates one way students retain their own beliefs: they simply juxtapose them with a new belief. Unless students practice expressing and defending their own beliefs, and listening critically to those of others, they will not critique their own beliefs and modify them in light of school learning. "As children
discover they have different solutions, different methods, different frameworks, and they try to convince each other, or at least to understand each other, they revise their understanding in many small but important ways.  

Science texts suffer from serious flaws which give students false and misleading ideas about science. Students are not encouraged to develop real experiments; rather, they are told what is true and false and given demonstrations to perform. Typical science texts present the student, in other words, with the finished products of science. These texts present information and tell students what is so. They have students sort things into pre-developed categories, rather than stimulating students to discover and assess their own categories. Texts require students to practice the skills of measuring, graphing, and counting, often for no reason but mindless drill. Such activities merely reinforce the stereotype that scientists are people who run around counting and measuring and mixing bizarre liquids together for no recognizable reason.

Texts also introduce scientific concepts. But students must understand scientific concepts through ordinary language and ordinary concepts. After a unit on photosynthesis, a student who was asked, "Where do plants get their food?" replied, "From water, soil, and all over." The student misunderstood what the concept 'food' means for plants and missed the crucial idea that plants make their own food. He was using his previous (ordinary, human) concept of 'food'. Confusion often arises when scientific concepts that have another meaning in ordinary language (such as, 'work') are not distinguished in a way that highlights how purpose affects use of language. Students need to see that each concept is correct for its purpose.

Students are rarely called upon to understand the reasons for doing their experiments or for doing them in a particular way. Students have little opportunity to come to grips with the concept of 'the controlled experiment' or understand the reasons for the particular controls used. Furthermore, texts often fail to make the link between observation and conclusion explicit. Rarely do students have occasion to ask, "How did we get from this observation to that conclusion?" Scientific reasoning remains a mystery to students, whereas education in science should combat the common assumption that, "Only scientists and geniuses can understand science."

To learn from a science activity, students should understand its purpose. A critical approach to science education would allow students to ponder questions, propose solutions, and develop and conduct their own experiments. Although many of their experiments would fail, the attempt and failure provide a valuable learning experience which more accurately parallels what scientists do. When an experiment designed by students fails, those students are stimulated to amend their beliefs.

Many texts also treat the concept of "the scientific method" in a misleading way. Not all scientists do the same kinds of things — some experiment, others don't, some do field observations, others develop theories. Compare what chemists, theoretical physicists, zoologists, and paleontologists do. Furthermore, scientific thinking is not a matter of running through a set of steps one time. Rather it is a kind of thinking in which we continually move back and forth between questions we ask about the world and observations we make, and experiments we devise to test out various hypotheses, guesses, hunches, and models. We continually think in a hypothetical fashion: "If this idea of mine is true, then what will happen under these or those conditions? Let me see, suppose we try this. What does this result tell me? Why did this happen? If this is why, then that should happen when I ...."

We have to do a lot of critical thinking in the process, because we must ask clear and precise questions in order to devise experiments that can give us clear and precise answers. Typically the results of experiments — especially those devised by students — will be open to more than one
interpretation. What one student thinks the experiment has shown often differs from what another student thinks. Here then is another opportunity to try to get students to be clear and precise in what they are saying. "Exactly how are these two different interpretations different? Do they agree at all? If so, where do they agree?"

As part of learning to think scientifically, clearly, and precisely, students need opportunities to transfer ideas to new contexts. This can be linked with the scientific goal of bringing different kinds of phenomena under one scientific law, and the process of clarifying our thinking through analogies. Students should seek connections, and assess explanations and models. "How do the concepts of gravity, mass, and air resistance explain the behavior of pebbles and airplanes, boulders and feathers?"

Finally, although scientific questions have only one correct answer, they may have a number of plausible answers only one of which is correct. It is more important for students to get into the habit of thinking scientifically than to get the correct answer through a rote process that they do not understand. The essential point is this: students should learn to do their own thinking about scientific questions from the start.

Once students give up on trying to do their own scientific thinking and start passively taking in what their textbooks tell them, the spirit of science, the scientific attitude and frame of mind, is lost. Never forget the importance of "I can figure this out for myself! I can find some way to test this!" as an essential scientific stance for students in relationship to how they think about themselves as knowers. If they reach the point of believing that knowledge is something in books that people smarter than them figured out, then they have lost the fundamental drive that ultimately distinguishes the educated from the uneducated person.

Unfortunately, this shift commonly occurs in the thinking of most students some time during elementary school. We need to teach science, and indeed all subjects, in such a way that this shift never occurs, so that the drive to figure out things for oneself does not die, but is continually fed and supported by day to day scientific thinking on our part.

From the outset we must design science activities so that students cannot mindlessly perform them. We should look for opportunities that call upon students to explain or make intelligible what they are doing and why it is necessary or significant. When students perform experiments, we should ask questions such as these:

- What exactly are you doing? Why? What results do you expect? Why? Have you designed any controls for this experiment? (Why do you have to use the same amount of liquid for both tests? Why do these have to be the same temperature? Size? What would happen if they weren't?) What might happen if we ... instead?

When students make calculations or take measurements, we should ask questions like these:

- What are you measuring? Why? What will that tell you? What numbers do you need to record? In what units? Why? What equation are you using? Why? Which numbers go where in the equation? What does the answer tell you? What would a different answer mean?

When studying anatomy, students can apply what they learn by considering such questions as these:

- If this part of the body has this function, what would happen if it no longer functioned fully or at all? Why do you say so? What would that be like for the person? What if it functioned on "overdrive"? What other parts of the body would such breakdowns affect? Why?
When students use theoretical concepts in biology or zoology, for example, they could be asked to explain the purpose and significance of those concepts by answering questions like these:

- How important is this distinction? Let's look at our chart of categories of living things. Where on the chart is this distinction? Why? What distinction is more important? Why? Less important? Why? (Why is the distinction between vertebrates and invertebrates more important to zoologists than the distinction between warm-blooded and cold-blooded animals?)

- Did any categorizations surprise you or seem strange? Do zoologists group together animals that seem very different to you? Which? How can we find out why they are grouped this way?

In general, students should be asked to explain the justification for scientific claims.

- Why does your text say this? How did scientists find this out? How would that prove this conclusion? Could we explain these results another way? What? Then how could we tell which was right? What would we have to do? Why? What results would you expect if this were so, rather than that hypothesis?

Of course, all of the questions above need to be modified in the light of the grade level, the particular students, and the context. We must continually take into account precisely what questions in what form will stimulate their thinking. We want to make sure that we don't overwhelm them with questions they are not able to handle, for that will cause them to stop thinking as quickly as the straight didactic approach does.

In sum, whenever possible, students should be encouraged to express their ideas and try to convince each other to adopt them. Having to listen to their fellow students' ideas, to take those ideas seriously, and to try to find ways to test those ideas with observations and experiments are necessary experiences. Having to listen to their fellow students' objections will facilitate the process of self critique in a more fruitful way than if they are merely corrected by teachers who are typically taken as absolute authorities on "textbook" matters. Discussion with peers should be used to make reasoning from observation to conclusion explicit and help students learn how to state their own assumptions and recognize the assumptions of others.

Footnotes


What Biome Do You Live In

Objectives of the remodelled lesson
The students will:
- through discussion, explore the concept 'biome,' the usefulness of distinguishing biomes, and historical implications of the concept

Original Lesson Plan

Abstract
Students use the high and low temperatures and the average annual amount of precipitation for their towns and a table to identify their biome. They then compare their towns with the description of their biome in the text, and explain differences.

from Silver Burdett Science 6th Grade by
George G. Mallinson, Jacqueline
Mallinson, William L. Smallwood,

Critique
The lesson encourages independent thought by having students compare their area with the description, and speculate on reasons for any differences. We would extend this discussion. The lesson also offers an opportunity for interdisciplinary work by exploring the relationship between geography and history.

Strategies used to remodel
S-1 thinking independently
S-17 questioning deeply: raising and pursuing root or significant questions
S-23 making interdisciplinary connections

Remodelled Lesson Plan

The teacher, rather than immediately assigning this page, could first ask students how they could find out what biome they live in. "What do you need to know about an area? (Review the concept.) How could we find those things out?" S-1

When students have identified the biome, use the questions in the original lesson, extended with questions like the following: Why is that our biome? What is different here? Which differences are natural? Man-caused? If different places that have the same biome vary in these kinds of ways,
why do we classify biomes? Does knowing which biome we belong to tell us anything? What? How can we use our knowledge about biomes? S-17 Why do other places have our biome?

To have students make interdisciplinary connections, you could ask, “How does an area’s biome affect the history of that place? Why? Identify the biomes of places we have studied in history. Would that history be different if that place had been tundra? Desert? How? Why?” S-23
The Human Skeleton

by Evelyn De La Paz Rios, Rice Elementary School, San Carlos, CA

Objectives of the remodelled lesson

The students will:

- make their preconceptions about the skeleton explicit by drawing it
- draw another skeleton after learning more about it, thereby examining, evaluating, and modifying their preconceptions

Standard Approach

The students' text has a brief discussion of the human skeleton with the names of the different bones.

Critique

Children in the elementary grades have certain ideas about the human body. Some of these ideas are correct and some are not. We must give children the opportunity to correct those which are incorrect by comparing what they do know with what they do not know and actively make their own modifications.

Strategies used to remodel

S-1 thinking independently
S-30 examining or evaluating assumptions
S-33 evaluating evidence and alleged facts

Remodelled Lesson Plan S-1

The students will be divided into partners and will take turns drawing each other's body outline as the person lies on the paper. After drawing the outlines, the students will exchange papers with their partners so that everyone will have an outline of his or her body. Without referring to a text book, each student will draw his or her skeleton in the outline. These drawings will hang in the room while the students gather information about their bodies, comparing it to other animals, machines, and artificial parts.

As students gather the information, they will record and map it out on a second body outline. By critiquing their initial ideas, the students will have a better understanding of the process of expanding their information base. S-30
The students will construct a model of a 5' skeleton using plaster of paris, old sheets, and cardboard tubes. The students will work in groups of 2, 3, or 4 to construct some part of the skeleton. After constructing the parts of the skeleton in proportion to the whole, they will assemble the skeleton.

With the modified knowledge about the human skeleton and the interest and humor engendered by making the models, students will be asked to write some creative response: a short comedy, a mystery, or perhaps a poem.

**Editor's note:** What were you right about? How did you know those things? What were you wrong about? Why did you think that? How could you have been wrong? S-33

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Follow up brainstorming sessions with discussion of the items listed — categorizing, evaluating, analyzing, comparing, ordering, etc.
Hair Keeps Animals Warm

Objectives of the remodelled lesson
The students will:
• discuss the importance of controlling variables when experimenting, by analyzing the experiment in their texts
• evaluate the model used by the text for its experiment design by discussing significant similarities and differences

Original Lesson Plan

Abstract
Students remove the labels from two tin cans. They glue cotton around one of them and fill both with the same amount of hot water. They predict the results and then measure and record the water temperature every five minutes for half an hour. The conclusion reads, "Using the results from this experiment, explain how hair keeps an animal warm." As an extension, they are to consider how sea mammals with little hair keep warm.


Critique
This lesson affords the opportunity for students to critique their texts. It inadvertently encourages sloppy thinking in students. It does not answer the question it claims to. Though the title question is "How does hair keep an animal warm?" all that can be inferred from this experiment is that stuff similar to hair retains heat. It does nothing to explain how, it merely suggests that hair (or cotton) helps keep animals warm. Students are likely to answer the question with a restatement of what it asks, that is, "Hair keeps animals warm by keeping the heat in."

The lesson offers a number of opportunities for infusing critical thought. Students could explore and evaluate the analogy between the cans of warm water and animals. Critical vocabulary use can be reinforced. The extension about how sea mammals keep warm could be further extended with a discussion of people and reptiles.

Strategies used to remodel
S-21 reading critically: clarifying or critiquing texts
S-33 evaluating evidence and alleged facts
S-29 noting significant similarities and differences
S-10 refining generalizations and avoiding oversimplifications
Remodelled Lesson Plan s-21

Students could read the experiment, and discuss its design at length. For example, you might ask, "Why fill the cans from the same container? What could happen if you didn't? How would that affect the results? Why do both cans have to have the same amount? Why make a graph? Could the data be organized another way instead? Which is best for this kind of information? Why? How would you expect the experiment to turn out? Why? What kind of answer would you give to the question? What did the experiment show? Why? What did it claim to show? Are these the same or different? S-33 Why? What is used in place of the animal? Its fur? How like and unlike are cans of warm water and cotton to animals and fur? Are the similarities relevant to the question the experiment poses? Are the differences? Assess this experiment." S-29

Finally, students could consider less hairy mammals and animals. "Does hair help keep all animals warm? Name some animals that have little or no hair. How do they keep warm?" S-10
Magnets

Objectives of the remodelled lesson
The students will:
- explore and clarify ‘magnetism’ through play and structured activities
- transfer what they learn about magnets to their understanding of the Earth

Original Lesson Plan

Abstract
The article containing the following suggestions emphasizes the importance of students’ “playing” with magnets before the formal lesson begins. The author then suggests the following activities: students are given a variety of objects to test for attraction to magnets; students distinguish metals that are attracted from those that aren’t; students devise tests which determine relative strengths of magnets; students make magnets; and students use magnets to find objects buried in sand.

from Learning Magazine Vol 15, #7
“Science — Discover the Wonder,” by G.
Douglas Paul pp. 44-45.

Critique

The first, third and fourth activities, as well as the introduction, encourage independent thought. It is unclear, however, whether or not students are to discuss their findings. The lesson does nothing to put the concept of magnetism into the larger picture of science. It misses the chance to discuss the purpose and applications of the object of study. Ships and airplanes use compasses, which rely on magnetism, to navigate. Magnetism is an important idea in astronomy.

Strategies used to remodel
S-1 thinking independently
S-11 comparing analogous situations: transferring insights to new contexts
S-23 making interdisciplinary connections
S-5 developing intellectual humility and suspending judgment

Remodelled Lesson Plan

This lesson could start with a discussion to find out what students already know about magnetism and its uses. Instead of giving students objects to test, students should be able to decide what to test and how to determine the attraction to the magnet. S-1 This lesson does a good job when it transfers
learning to the situation of making magnets, but it would do well to make this transfer explicit by asking students what more they have learned from making magnets, than from studying those already made.

Discuss a compass with students, explaining what it is used for. Let students play with compasses, or make them, and see how the magnet affects them. "Why does the compass needle usually point one way? Why does your magnet change that? What does that tell us about the Earth?" Students could be asked to describe or sketch the shapes of the magnetic field as discovered by noting where magnets attract and repel each other. They could look up drawings of the magnetic field around the Earth and compare the two. S-11

As an extension exercise, students could discuss why we use the expression 'magnetic personality' and what it means. The teacher could lead a discussion where the children try to puzzle this out. S-23

Finally, this lesson can be wrapped up by asking students to review what they have learned. They should be able to state what they now know and what they are uncertain of in the area of magnetism. "What kind of 'thing' is magnetism? Can we sense it? How do we know it's there? What do we know about it? What questions do you have about magnets and magnetism?" S-5 Interested students could research magnets and report back to the class.
Polar Ice Caps Melt

Objectives of the remodelled lesson
The students will:
• design a model to explore the consequences of the melting of the polar ice caps
• evaluate their models by noting significant similarities and differences

Original Lesson Plan

Abstract
This lesson focuses on the question, "If the polar ice caps melt, what would happen to the rest of the world?" Students put sand, water, and a large chunk of ice in a large pan, and record periodic observations while the ice melts. They discuss the following questions: In what way is the model similar to what happens on Earth? What kinds of errors occur when any model is used?


Critique

This lesson provides an opportunity for model design and assessment, distinguishing relevant from irrelevant differences, differences in style of observations, and an exploration of a chain of causes and effects.

Strategies used to remodel
S-9 developing confidence in reason
S-1 thinking independently
S-31 distinguishing relevant from irrelevant facts
S-35 exploring implications and consequences
S-11 comparing analogous situations: transferring insights to new contexts
S-29 noting significant similarities and differences

Remodelled Lesson Plan s-9

You could begin by asking students what they think would happen if the polar ice caps melted. Guide them in designing a model to answer the question, with questions like the following: How could we find out, without it actually happening? How could we make a model we can watch? What could we

During the course of the study, have students write down their observations (and times at which they made them). A student could put the observations in chronological order. Students could discuss their observations, and what they imply: What has happened? What did different students find? How can we compare these notes? (The class could use the notes to make a composite description, which would probably be more complete than that of any single student. Students could discuss differences between observations near the same time. Students could delete irrelevant observations.) S–31 How is our model like what the real situation would be? Unlike it? What does that tell us about what would happen if the ice caps really melted? Follow up responses to elicit further effects. (Then what? What effect would that have?) Students could discuss affects on land, climate, people, and other forms of life. S–35 The class could also discuss the question: What would happen if the ice caps grew? (Discuss at length.) S–11

The teacher could supplement the discussion of the worth of the model, with questions like the following: Why did we have to make a model to explore this question? In what ways was the model different from Earth? Which of these differences are relevant to our key question? How useful was the model? What might we have done, if we had the time and resources, to make the model more accurate? Why would that have been better? Do we need to have done that, or can we draw conclusions from our model? S–29

If students know about the ice ages, they could be brought into the discussion of this lesson. Students may be able to speculate about how scientists know the ice caps have changed sizes. “Given what we’ve learned about how the Earth would be affected by the melting of our ice caps, what could we expect scientists to find if ice caps had melted and grown a long time ago? If the ice caps used to be smaller (larger), what evidence would be left? How do scientists know how big the oceans used to be? If the oceans shrank (grew) what would coasts look like?” S–11
Making Models: The Atom

Objectives of the remodelled lesson
The students will:
- analyze the concept 'model' by discussing models they have seen and discussing the purposes of models
- develop criteria for evaluating models
- design and make models of an atom
- discuss the strengths and weaknesses of their models of atoms, noting significant similarities and differences

Original Lesson Plan

Abstract
Students examine pictures of models of atoms, are provided with materials, and are asked to make their own models of oxygen, carbon, or sodium atoms. They are asked if they can make the electrons revolve.

from Concepts in Science 6th Grade by Paul F. Brandwein, Elizabeth K. Cooper, Paul E. Blackwood, Elizabeth B. Hone. p. 293.

Critique
This lesson fragment offers an opportunity for students to discuss the purposes of models in general and the specific benefits of making models of atoms. Students can also practice assessing models, in light of those purposes. By examining their models at length and in great detail, students can develop their clarity of thought and expression, and review what they know about atoms.

Strategies used to remodel
- S-29 noting significant similarities and differences
- S-15 developing criteria for evaluation: clarifying values and standards
- S-14 clarifying and analyzing the meanings of words or phrases
- S-1 thinking independently
- S-8 developing intellectual perseverance
- S-10 refining generalizations and avoiding oversimplifications
- S-31 distinguishing relevant from irrelevant facts
- S-23 making interdisciplinary connections
Remodelled Lesson Plan s-29

The class could begin by discussing models in general and analyzing the concept. "What does 'model' mean? What models have you seen or made? Did they help you understand what they modeled? How? Why? How can you tell a good model from a poor model? What's an example of a good model? Why? A poor one? Why? S-15 What differences were there between models you have seen and the things they modeled? (Ask this of several of the examples previously given.) Why make models? What purpose do they serve?" S-14

Tell students that they are going to make models of atoms. Have students discuss what they know about atoms, and ask, "How could models of atoms help us? How could we make a model of an atom?" You might ask them what parts they would need, and how they could put them together. S-1 Students could make and evaluate various models of atoms and engage in an extended process of designing, making, discussing, and improving models of atoms. S-8

Students could be led in a discussion of the strengths and weaknesses of various models, with questions like the following: (Of each proposed model ask,) What parts does it have? What parts do atoms have? Does the model have any extra parts? Does it leave out parts? How is each part of this model like the part of the atom? (Continue for each part, including the connecters.) Unlike? (Encourage multiple responses.) Could this model be improved? How? How do these models help us? How could they mislead us? How can we avoid being misled? S-10 Do these models help you understand atoms? How, or why not? Do any of these models suggest questions about atoms? What? Do the models help you find answers to those questions? Why or why not? Are the differences between the model and the atom relevant to the question you asked? Why or why not? S-31 How could this model be improved? Why would that improve it?

The teacher could use the idea of models to clarify the concept 'analogy'. Have students recall analogies. Have them compare models and analogies. (A model is a thing, analogies are words. Both have similarities and differences to the originals. Both can be evaluated in terms of their purposes and whether relevant features are similar or different.) S-23
The Sun Heats the Earth

Objectives of the remodelled lesson
The students will:
• infer how surface temperature affects air temperature
• exercise independent thought by organizing their data on weather, and answering essay questions
• use insight into numbers to understand a scientific phenomenon

Original Lesson Plan

Abstract
"How Weather Begins" discusses solar energy and its relationship to the Earth’s weather. This section explains how the warmth of the sun heats the atmosphere unevenly. One of the reasons for this is illustrated by an experiment in which students predict and observe which materials heat the most and least, and which lose heat the quickest and slowest. Another activity has the teacher shine a flashlight straight onto paper, then at an angle. Students compare the areas. The text relates the demonstration to the difference between summer and winter sunlight.

from Silver Burdett Science 5th Grade,
George G. Mallinson, Jacqueline Mallinson, William L. Smallwood,
Catherine Valentino. ©1985 pp. 260–261

Critique
The text confusingly infringes, with remembering and sensing. Examples of this problem occur on teachers’ notes on pp. 260, when students are asked to infer, conclude or figure out facts just mentioned in the text or described by students. For example, after discussing experiences of walking barefoot on hot and cool surfaces, students are to conclude that some of the surfaces were cooler than others. When you step from a hot surface to a cool one, you sense the latter is cooler; you do not conclude it.

The motivation exercise in the teachers’ notes on p. 260, about walking barefoot, is not terribly motivating and is a poor introduction to the text. Although it does illustrate that some surface areas are warmer than others, it does not engage students in the way the experiment for this idea does. This experiment is a hands-on illustration of the preceding text and is thus more dynamic than the proposed motivation. Even if this option is not exercised, a more exciting motivation scenario could be explored.

The enrichment suggestion on p. 261 (wherein the teacher is supposed to demonstrate that light shown at an angle covers more area, and thus provides less energy per unit of space), falls short of fully illustrating the concept. Students need to consider the demonstration carefully and make its meaning explicit.
Strategies used to remodel

S-32 making plausible inferences, predictions, or interpretations
S-23 making interdisciplinary connections
S-1 thinking independently

Remodelled Lesson Plan

Rather than opening the chapter with a questionable inference (that palm trees imply tropical places), it would be better to ask students what weather is and what they know about it. You could substitute the experiment on how heat affects different surfaces for the “motivation,” and ask students what surface temperatures might have to do with weather. “How is surface temperature related to air temperature?” S-32

The reasoning behind the enrichment activity for the different angles of sunlight could be made more explicit by eliciting or explaining that when the same amount of energy hits a smaller versus a larger area, the amount of energy per unit of area is greater. Here, students could be reminded of work with fractions. Write a fraction on the board, labeling the numerator ‘amount of energy’ and the denominator ‘area’. Write a second fraction, labeled the same, but with a larger denominator. Thus, students can understand the idea mathematically, as well as verbally. S-23

Ask students if they can design other models to illustrate this concept. If they do not suggest any, suggest a few yourself (both adequate and inadequate) to check their understanding of the concept. For each model, ask if it does indeed show how the angle of sunlight affects the intensity of heat. Probe their answers; insist they not only answer but explain why or why not. (They may need two models: one for “Energy which arrives at an angle covers more space,” another for “The same energy hitting more area provides less energy per area.”) S-1
Animal Architects

by Brooke Bledsoe, Napa U.S.D., Napa, CA

Objectives of the remodelled lesson
The students will:
• use resource material to support a conclusion
• develop and give arguments
• assess the arguments given

Original Lesson Plan
I made the remark in class to my fifth grade students that "Birds are the best architects, and we have always studied them to learn how to create better designs for our own buildings." One of the students interjected that he had always thought beavers were the best architects.

Based on this impromptu difference of opinion, I assigned a discussion for the following Friday to take place between those who took the "birds" side versus those who took the "beavers" side.

They could bring in all the reference material they could gather, and I recommended that they meet as a group before they got started in order to organize what they needed and how they would proceed.

On Friday afternoon, we set the classroom up with a row of desks for the "birds" opposite a row of desks for the "beavers". Those who did not want to participate, or who were undecided, sat in a row at the end of the classroom between the two opposing sides. I challenged them to listen to the arguments and facts and to decide which side they thought presented the best arguments and which side they would finally agree with. They could form a third side or have individual opinions.

As the discussion progressed, I observed that the students had set a pattern of debate that was quite civilized, allowing alternate views to be voiced in the order in which they sat. It reminded me of the Presidential debates on television in which one candidate is allowed so much time to address a question and then the other takes a turn to answer the same question. I intervened here to encourage responses from any member of a team, out of seating order, to counter or challenge something said from the other side.

The "beavers" definitely out-argued the "birds". They were more logical, had stronger data, and used more quotes from authority. However, with my intervention, the question changed then to, "Were the beavers, perhaps, the better engineers, and the birds the better architects?"

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I was very proud of the "undecided" group when I called time. They concluded that, although the "beavers" had made a much stronger case than the "birds", they really didn't prove the beavers were better architects, but rather that they build stronger houses. They also concluded that, since the beavers build only two types of houses, the variety of style and usefulness of the birds' nests, adapted to many environments, make the birds better architects and the beavers better engineers. My pride in the conclusions from my neutral group was due to their ability to see the difference between a stronger presentation, versus actual proof of the argument — a giant step towards critical thinking for ten-year-olds.

Critique

Other than curriculum content set out by the California Framework, I have pretty much left the textbooks and all workbooks behind in my mode of teaching. Thus, I am using my own logic to set forth methods to be used to teach the content prescribed. My plans and methods lack clarity and focus. Consequently, when using a situation that arises spontaneously, I need to progress in a logical order instead of shooting from the hip so much of the time. I feel as my clarity and focus crystallize, so will that of my students. The use of criteria and the clarification of vocabulary should be a starting point before sending the students to the reference materials.

Strategies used to remodel
S-26 reasoning dialectically: evaluating perspectives, interpretations, or theories
S-1 thinking independently
S-31 distinguishing relevant from irrelevant facts
S-34 recognizing contradictions
S-22 listening critically: the art of silent dialogue

Remodelled Lesson Plan S-26

I would use the same question: "Are birds better architects than beavers, or are beavers better architects than birds?" S-1 Again, I would divide the children into the three groups described above: the "birds", the "beavers", and the "undecided". I would give them two days to meet and to gather reference material, but this time I would advise them that at any time during the debate they could change their minds. One could become undecided or one could change to the other side and back again if any doubt entered his or her mind. Through open-ended questioning from me, I would ask for clarification of 'architect' and 'engineer' and see what they would do with these terms. S-31 I would choose a few comments from the two panels and ask if they really related to the argument, and I would select out any contradictions made by a side and hold them up for scrutiny. S-34

editor's note: The undecided students could also ask questions of the panellists. S-22
Parachutes and Other Falling Objects

Objectives of the remodelled lesson
The students will:
- design and test parachutes
- discuss characteristics which affect the descent rates of parachutes
- transfer insights about parachutes to falling objects in general and to falling objects on the moon
- hypothesize, test, and refine hypotheses regarding the descent rates of objects

Original Lesson Plan

Abstract
This lesson focuses on the key question, "What is the rate of descent of your parachute?" Students design, build, and test parachutes (twice each from three different heights), calculating the rates of descent in meters per second. They then discuss the following questions: What things affect the rate of descent? Did the rate of your chute change from one height to another? Why? Select the five slowest rates of descent and the five fastest from the class chart. Have those students display and describe their parachutes. Were there similarities? What can you conclude? How would you modify your parachute to improve its performance?

Critique
A major weakness of this lesson is its failure to connect why a parachute works to falling objects in general. It misses the opportunity to teach important science concepts such as gravity, wind resistance, and inertia. This trivializes the lesson by restricting it to measuring and recording data.

This lesson offers the opportunity to have students engage in extended scientific reasoning — posing questions, testing answers, posing new questions, and conducting further tests, all the while, assessing their original ideas and refining their initial generalizations. Headway can be made on the broadened topic without extended preparation, no measurements, and little recording of data.
Strategies used to remodel
S–8 developing intellectual perseverance
S–32 making plausible inferences, predictions, or interpretations
S–11 comparing analogous situations: transferring insights to new contexts
S–10 refining generalizations and avoiding oversimplifications
S–5 developing intellectual humility and suspending judgment
S–9 developing confidence in reason

Remodelled Lesson Plan s–8

Begin by asking if anyone knows what a parachute is and what it is for. Students should know that a parachute is designed to keep something from falling too quickly, that is, that it slows the rate of descent. “What affects the rate of descent of a parachute? How could we find out? How does a parachute work? Why does it work?”

Students could then design and test their parachutes. Students may repeat their tests on different days and/or in different places (windy vs. protected) and compare results. As in the original lesson, have them compare slow with fast parachutes and speculate on which differences affected the descent rate. They could compare parachutes of different materials, and those carrying different weights and shapes. Ask them, “What does this tell us? About air? Gravity? Objects? Why did we get the results we did? Why does the parachute fall slowly?” Students could then begin making generalizations and hypotheses, and designing experiments to test them. S–32

You could then broaden the original question to, “What affects the rate of fall of objects, and why?” S–11 Students could practice making and refining generalizations. Suggest that they experiment with other kinds of falling objects such as paper planes, feathers, books, rocks, pillows, etc. Students need not measure, they could simply group objects in general categories of fast-falling, slow-falling, and in-between-speeds. After each test or each few tests, discuss results, eliciting complete explanations. “What were you testing for? (To see if weight, size, or density affects fall rate.) What did you do? (Dropped this and that from the same height at the same time and place.) Why? (If what we tested for affects fall rate, since they're the same in every way but this, then this should have fallen much more slowly than that.) What happened? (This fell much more slowly than that.) What does that mean? Could there be another explanation? Were there other differences between the two objects that could have accounted for the results? How do these latest findings compare with our earlier tests? What other questions could be asked? Is there anything else that you noticed that would explain the results? What else could you test for? Now what would you say affects descent rates? Why? What doesn’t affect descent rates? Why?” S–10

The class could keep notes on the discussions, listing ideas, tests, and conclusions. The teacher could, perhaps during the summary, point out tests or hypothesis that failed or were proven wrong, but from which students learned something. S–5 Students could use the class records to sort slow, medium,
and fast falling objects, and write short passages comparing the three kinds of objects, trying to generalize from them, and speculating on the reasons for or principles behind the results. S-9

The material in this lesson could be related to botany with a discussion of different shaped seeds and seed containers, and how well they scatter seeds. Students could discuss objects falling on the moon. If necessary, first point out to students that the moon has less gravity, and less air. Students could compare how different objects (for example a rock versus a feather) would fall on the moon as opposed to Earth. S-11
Animals With Backbones

by JoAnne Rains, Clinton, South Carolina

Objectives of the remodelled lesson
The students will:
- apply the concept of classification
- discuss animals with and without backbones and develop working definitions of vertebrate and invertebrate
- make other classifications within the vertebrates

Original Lesson Plan

Abstract
This chapter is called "Animals with Backbones". The concept of classification is taught at the beginning of the chapter, using some photographs that were not very clear. Students were asked, "How many animals can you name? Where would you see a lot of different animals? How could you group them?" The teacher's textbook suggests asking the student what 'classification' means and then relating the word to groupings, etc. The text shows a picture and tells the student, "All these animals are vertebrates." Then it names a group of invertebrates. The text continues telling facts.


Critique

I think that this lesson uses an illogical order. However, I do like the operational definitions followed by the use of the word several times in context.

The text misses several opportunities to use an inductive approach or discovery method of learning. The text asks, "If you go to a zoo, how would you find the birds?" Then it answers, "They are found in a section of the zoo called an avairy." This question does not lead the questioner in the proper direction. This question-and-answer sequence is followed by several similar sequences that bring in irrelevant material and are illogical in nature. The textbook is unclear in its reference to certain pictures. It provides misinformation concerning many of the illustrations. The questions always use a didactic approach in discussing vertebrate and invertebrate animals. The questions are overly simplistic for fifth grade students. For example, "How are you like a cat? How is a cat like a fish?"

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Strategies used to remodel

S-1 thinking independently
S-29 noting significant similarities and differences
S-23 making interdisciplinary connections
S-32 making plausible inferences, predictions, or interpretations
S-17 questioning deeply; raising and pursuing root or significant questions

Remodelled Lesson Plan

I would begin this class with the students' text books closed. This lesson could be introduced with an inductive approach using the following activity. I might start by asking random students to change seats until I had all the girls on one side and all the boys on the other side of the room. Then I would ask, “What have I done as I changed your seating arrangement?” They should probably respond, “You have all the girls sitting together and all the boys sitting together.” S-1 Then I would introduce ‘classification’ for the first time. I might say, “That’s great! Are you telling me that I have classified (divided) your class into two main groups that consist of boys and girls?” Then I would lead them into the idea of sub-groups by an exercise like the following. “Would all the blue-eyed girls stand up?” I would then allow the students to develop generalizations through discussion and questioning about the group as a whole and its various subgroups. These questions might be asked.

• How could we classify this whole group?
• How would you classify these persons who are standing up? What other groups do they belong to?
• What are some other ways that we can classify this group?
• What are some classifications that we find in real life?

If they have a problem getting started, I might give examples of dishes. Dishes can be classified into plates, cups, saucers, and bowls. Or that contact sports might be classified. “Can you tell me what other sports would fit into this classification?”

Using the text and supplementary materials, I would next examine pictures of vertebrates and invertebrates. I would guide them through questioning into their classifying the animals into the broad categories. After they have classified them, I would ask the following questions:

• How are these animals alike?
• What is there about this animal that kept you from putting it in this other group or classification? S-29

At this point I would develop the definition of ‘vertebrate’ and ‘invertebrate’. I could say, “I will label this group ‘vertebrates’.” Then I would ask, “Why should they be called vertebrates?” Since they have already studied the human body, I hope that they would pick up on the connection of our backbone. After this connection has been made, I would write the word “invertebrate” on the board. Here a reference could be made to a recent language arts lesson on prefixes. S-23 I would ask, “Do you recall from our reading lesson what the prefix ‘in’
means?” With that information and the information of what a vertebrate is, what might we infer about the word ‘invertebrate?’ S-32

At this point, since the distinction between the vertebrates and invertebrates has been explored, I would spend the rest of the class period on vertebrates and deal with invertebrates in the next class period.

editor’s note: Instead of the above initial activity, to have an introduction more relevant to the lesson, students could brainstorm a list of animals, and categorize them, while being introduced to ‘classification’. (You may have to participate in the brainstorming and suggest things like frogs, eagles, and starfish, since students may be thinking of mammals only.) Students could also categorize the list into groups and sub-groups to develop a hierarchy of categories analogous (and probably remarkably similar) to scientists’. The teacher could then segue into the lesson by saying that scientists have some of their own categories. Then introduce the word ‘vertebrates’ and ask students if the word sounds or looks familiar. “Why is this such an important distinction to zoologists?” S-17
Measuring Calories

by Theresa A. Barone, Covington Middle School, Birmingham, MI

Objectives of the remodelled lesson
The students will
- learn what ‘calorie’ means
- design and conduct experiments to determine calorie counts
- examine the reasons for the math they use
- develop ways of recording and presenting their data

Original Lesson Plan

Abstract
This teacher demonstration illustrates that a calorie is a unit of heat given off when a fuel, such as our food, is burned. The illustration of and directions for making a simple calorimeter are provided. A flask with a measured amount of water is placed on a ring stand or other support and the water temperature is recorded. Around the base of the flask, a protective shield from asbestos pads or aluminum foil is made. This shield prevents heat loss. The amount of heat given off in the experiment is calculated by determining how much the water temperature rises. It is suggested that the meat of a walnut or peanut be used as the heat source. The nut meat is lighted and placed under the flask of water in the shield. As soon as the nut is burned, take the water temperature again. The calorie content of the nut can then be calculated.


Critique

The design of this demonstration allows for little or no student involvement. The students are not asked to think about any of the concepts involved, they are simply shown them. The lesson does not require the students to ask any questions about what a calorie is. The concept of calorie is also not related to any other concept, including food consumption or diet. Although the students are asked to calculate the calorie content of the nut, no mention of relating science to math is mentioned. Also when the students calculate the calories of a given food, the data should be put in a form useful to others. This lesson makes no mention of this important extension. Finally, a science lesson lends itself naturally to the discussion of variables and how to alter the experiment in order to minimize them: the concept of the controlled experiment. This lesson does not mention this idea either.
Strategies used to remodel

S-1 thinking independently
S-23 making interdisciplinary connections
S-35 exploring implications and consequences
S-33 evaluating evidence and alleged facts
S-5 developing intellectual humility and suspending judgment
S-27 comparing and contrasting ideals with actual practice

Remodelled Lesson Plan

This lesson will begin by asking students to put their prior knowledge to work. The students could begin by discussing what they already know about how people get energy and by looking up the definition of 'calorie'. Questions that can be asked might include: Where do people get energy? Can you get more energy and become healthier by eating huge amounts of food? What is used to measure the amount of energy in foods? Why is it important to consider calories when discussing proper nutrition? How are calorie counts made? S-1

Through the teacher's guidance it should be established that calorie counts of common foods are determined by actually burning food and measuring the heat energy the food gives off. Tell students that a calorimeter is an instrument that can measure the heat energy a food contains. Through discussion, ask the students to come up with the items they will need to make their own calorimeter. Begin by asking: How can we best test different foods? What will be the best materials to use that will give us the most accurate readings? What will we need to measure heat? How will the heat be measured? How will the heat be contained? What could throw off our results? What could affect the water temperature besides the burning food? What do we need to do to control these variables? How can we prevent these other things from messing up our results? S-1

Once the students have established all they need to set up their calorimeters, provide the materials for doing so. Allow them the opportunity to burn a variety of both foods and amounts.

After the data have been collected, discuss the importance of using the correct mathematical operations when arriving at their calorie counts, by having students discuss the equations at length. For example: What equation must we use? What number goes here? Why? How do we get this number? What do we do with that result? Did you add or subtract when measuring the difference in temperature? What would happen if you did not multiply the correct temperature change and the volume of water? S-23

Be sure to discuss the best way for recording their data and showing it so that others can learn from their experiments. How can we show our results? What are we showing? How should we arrange the data? What sort of graph can we use? What headings do we need? The data the students have collected is helpful when they discuss the implications for nutrition. Ask them how various foods counted. Which foods had higher or fewer calories? Why is this information valuable? S-35
editor's note: Instead of designing their own experiments from scratch (if they have never designed an experiment or discussed experiment design before), students could study the original lesson's design, and develop the concept of controlled experiments by discussing features of the original (and alternatives). “What is this step for? Why is it necessary? What could we do instead?”

Students could look up the word 'calorie' in reference books (texts, dictionary, books about energy, etc.)

Students who tested the same food can compare their results, and see if they can explain any differences. "Why did you get different results for the same food? Should they be different? How different were they? Did you do exactly the same thing? S-33 If those results are a bit off, could they all be just a bit off? What does that tell us?" S-5 Point out to students that scientific experiments don't come out perfectly. (You might explain the notation ± and why it's used.) S-27
Insulation

Objectives of the remodelled lesson

The students will:
- develop experiments to settle the question, “Does water cool at different rates in different containers?”
- discover and clarify related questions that their experiments do not answer
- practice using the critical vocabulary: inference, conclusion, evidence, and relevance
- distinguish relevant from irrelevant information to the problem
- make inferences from their experiments and evaluate them
- explore practical applications of insulation

Original Lesson Plan

Abstract

This lesson asks, “In which container (tin can or styrofoam cup) will the hot water retain its heat longer? Why?” Students pour equal amounts of water at the same temperature into the containers. They record the highest temperatures, and the temperature every minute for fifteen minutes. They make line graphs, individually and together. Under discussion topics, teachers are asked to “Encourage the students to draw conclusions about the relationship between the time it took the water to cool in one container compared to the other container.” The extension suggests that students could test several kinds of containers.


Critique

This lesson presents an experiment, rather than presenting a question and allowing students to design experiments, thereby failing to encourage students to engage in scientific reasoning. It also unnecessarily limits the containers used. Allowing students to propose and test different containers would help them broaden their understanding of which materials conduct heat and which insulate. Using only two materials prevents students from fruitfully attempting to make generalizations about insulation.

The lesson presents another opportunity for practicing critical thinking micro-skills by using critical vocabulary, distinguishing relevant from irrelevant evidence, and making and evaluating inferences. Furthermore, students could explore practical applications of insulation, thus applying the key concept to other situations (buildings, clothes, atmosphere).
Strategies used to remodel

S-9 developing confidence in reason
S-21 reading critically: clarifying or critiquing texts
S-1 thinking independently
S-13 clarifying issues, conclusions, or beliefs
S-19 generating or assessing solutions
S-17 questioning deeply: raising and pursuing root or significant questions
S-29 noting significant similarities and differences
S-10 refining generalizations and avoiding oversimplifications
S-35 exploring implications and consequences

Remodelled Lesson Plan S-9

A minor remodel of this lesson, would be to present the teachers' text to students, and have them explain why they are given those instructions. (Why does the temperature of the water have to be the same when the experiment starts? If it wasn't, how would that effect the results? Etc.) S-21 Thus, students could begin to develop for themselves a sense of how to design a controlled test. The discussion could be reviewed when students are later asked to design other experiments.

Instead of setting up the experiment for students, engage them in a discussion of hot water cooling. You might ask, "What happens when water cools? Where does the heat go? How fast does hot water cool off? What affects the rate at which water cools off?" S-1

To help students think independently by designing experiments, use questions like the following: How can we find out what materials best retain heat? What kinds of containers should we test? What characteristics of the containers might affect cooling rate? (size, shape, material, thickness) How can we test each characteristic? S-13 What units of measurement should we use? How can we make sure that the results are due only to what we are testing, and not influenced by other things? What, besides the container, could affect the cooling rate, or our measurements? How can we prevent that from affecting our results? What will we have to do? (All water should begin at the same temperature and containers should sit in the same temperature. If testing for shape, use two different shapes of the same size and material; if testing for material, use two different materials, of the same size and shape.) S-19

This discussion could also be used as an opportunity to teach the scientific method of hypothesis, controlled testing, observation, and inference, by providing these words during or after discussion.

Students could also themselves decide on good ways to record, organize, and report their observations though charts, graphs, or tables. (What information will we need to record? What were we testing for? How can you organize the results and present them clearly? What headings will you need?" etc.) S-1

Students could record cooling rates, or simply the time it took the water to reach room temperature. Students need to record times, temperatures, and a description of each container — its size, shape, and what it's made of. Students
could also engage in qualitative observation by periodically feeling the outsides of the different containers. This data could be helpful to students when discussing the implications of their findings.

When students have completed their experiments, ask them what they observed, and what they conclude or infer. Have them explain their answers and reasoning as fully as possible. Extend the discussion by using questions like the following: What differences did you find between the containers? Why did you find those differences? What is it about the containers that accounts for those differences? S-17 What containers gave similar results? Why? S-29

The teacher could rephrase student responses using critical vocabulary, and encourage students to use such vocabulary as, observe, infer, evidence, relevant, conclusion, and assume.

The teacher could extend this lesson by having students design and conduct experiments to test new ideas they expressed in the above discussion. Thus, students develop a clearer, more complete, and less stereotyped idea of what scientists do. S-10 Or students could merely pose and clarify unanswered questions. Perhaps interested students could conduct further tests and keep the rest of the class posted.

The class could then explore the importance of their experiments and findings in the direction of either science or practical application. To pursue the latter, consider asking the following questions: When is it useful to know what materials (shapes, sizes, etc.) hold heat? Let heat escape? 'Insulate' could be introduced, if not done before.) When do people need to know what materials insulate or conduct heat? Why? What other things do people keep in mind when choosing insulators or heat conductors? What other factors are relevant? (For example, why don't we wear styrofoam clothes to keep us warm? Can you think of ways that nature insulates? How do those examples relate to your experiments? Are natural insulators like any of the materials you tested? Which? How? How are they different? S-35

Students could summarize their results by completing such sentences as, "Heat travels more quickly through materials that are .... Heat travels more slowly through materials that are ...." and by writing brief explanations why. S-17
Rubber Bands

Objectives of the remodelled lesson
The students will:
- engage in Socratic discussion about their observations of and speculations about rubber bands
- design and conduct tests about how much different rubber bands stretch and how far they shoot, thus exercising independent thought
- clarify the concept of 'stretch'
- apply their new insights to other stretchy and rubbery things

Original Lesson Plan

Abstract
The first lesson, "Rubber Band Stretch", focuses on the key question, "How much does a rubber band stretch?" Students suspend paper cups from different kinds of rubber bands attached to boards by means of tape and paper clips. They add pennies to the cups and measure how much the different rubber bands stretch. They graph their data and develop a formula relating stretch to mass. The extension has students compare rubber bands of different characteristics.

The second lesson, "Rubber Band Shoot", has students discuss the key question, "How does a rubber band shoot?" Students then stretch the rubber bands measured amounts, and let go. They graph their data and discuss the results. In the extensions, students compare the behavior of different rubber bands, and devise a formula combining stretch and shoot formulas.

from Introductory Investigations,
Fresno Pacific College — Project Aims.
Arthur Wiebe and Larry Ecklund,
editors pp. 33–35.

Critique

These lessons offer a number of exciting opportunities. Both lessons, however, put too much emphasis on measuring and recording. Students could make fuller observations, begin to develop a sense of what goes on when rubber bands stretch, and discuss the relationship of stretch to shoot qualitatively.

"Rubber Band Stretch" is unnecessarily confusing. Mass doesn’t make rubber bands stretch, force does. Students should understand more clearly the reason for the design of this experiment. As given, the purpose of the test design is unclear. Nor does either lesson ask students to consider any application of what they have learned. No attempt is made to tie the information to other objects. Discussions of muscles, elastic, gum, and other stretchy things belong in this unit.
"Rubber Band Shoot" does not answer the question it purports to: "How does a rubber band shoot?" It succeeds in answering how far a rubber band shoots, and therefore confuses two distinct and very different questions.

**Strategies used to remodel**
- S-24 practicing Socratic discussion: clarifying and questioning beliefs, theories, or perspectives
- S-14 clarifying and analyzing the meanings of words or phrases
- S-29 noting significant similarities and differences
- S-13 clarifying issues, conclusions, or beliefs
- S-33 evaluating evidence and alleged facts
- S-1 thinking independently
- S-11 comparing analogous situations: transferring insights to new contexts
- S-21 reading critically: clarifying or critiquing text

**Remodelled Lesson Plan**

Before beginning the study of rubber bands, the teacher may want to lead students in a discussion regarding safety. Students could mention possible dangers and the best ways of avoiding them. We suggest an introductory lesson, since children love to play with rubber bands. This first lesson should be a chance for the children to manipulate and share observations about rubber bands. The teacher could record their findings and save them.

To begin the science unit, remind the class of their rubber band play. Ask them if they remember any of the ideas they mentioned. Discussion could be extended with questions like the following: What did you notice about rubber bands? (When necessary, elicit clarification.) What kind of rubber band was it? What, exactly, did you do? How did it look? Feel? Sound? Which of these things that you found, could we study? (Some students may want to explore ideas other than amount of stretch.) What differences did you find between rubber bands? Do you think the differences were related? How? Why? S-24

The class could discuss the idea of stretch and clarify it. What is stretch? What things stretch? How are all of these things alike? Different? S-14 Are there different kinds of stretch? S-29 How could we measure stretch? What might affect the measurements? What characteristics of rubber bands affect the amount of stretch? What kinds of rubber bands stretch the most? The least? How could we find out? What, exactly, should we measure? How? What do we need to record? How? Why?" S-13

At this point, the teacher could have students split into groups to design and conduct tests. The tests could then be discussed and evaluated. Students could then suggest and assess solutions to any problems they experienced while conducting or interpreting their tests. (For example, if students stretched a large and a small rubber band and simply measured the lengths, they wouldn't be able to distinguish later how much of the difference was due to stretchiness opposed to the original difference in length. Or different students may have gotten vastly different results, due to different amounts of force applied.) Such an experience would graphically illustrate the requirements of a well thought-out experiment. S-33
Or, the teacher could elicit design of a test similar to that in the book. "To stretch a rubber band, you need a force. To make accurate measurements, you need a way to control the force, so that results are due only to differences in the rubber bands, not to differences in force. What force can we use? If we pull, how can we be sure results won't vary because of different amounts of pull? We can't control or measure how much pull we use. Etc." Or students could analyze the original experiment. The teacher may want to have a wider variety of materials available than those mentioned in the original lesson.

Students could also decide on a reasonable method of presenting the data. Some may also demonstrate or reproduce their experiments.

Students could write a paper describing their question, experiments, hypotheses, data, observations, inferences, assumptions and conclusions.

Ask if this experiment suggests any important issues or questions and how we might go about settling them. They might think of ways to apply what they've learned about stretch. The teacher could bring out the list of stretchy things made earlier in the lesson, and have students discuss the items in terms of what they learned about rubber bands. They could elucidate similarities to and differences from rubber bands and try to predict the effects the differences might have in a similar study. "What does it imply about muscles and exercises, fitted sheets, pants with elastic waists, and pennies in your pockets?"

For the second lesson, you could ask students to share their questions about rubber band shooting. Each group or person selects one or more related questions and designs an experiment or study. Have students solve the questions of safety. Each study needs to address shooting method, means of observation, means of recording and presenting data.

Ask students to read the original lesson, and to do what they are asked in the lesson. Ask them the question, "How does a rubber band shoot?" If they answer with distances, ask them to consider their answer and decide what question they are really answering. They should see, or you can point out, that distances answer the question "how far" not "how" rubber bands shoot.

Discuss the relationship of stretch to shoot. "Were the stretchiest rubber bands the best shooters? Worst? Neither? Why do you think so? What were the best stretchers and shooters like?" It is interesting that the concept developed and measured in the first study became a variable in the second.

Relate rubber band "twanging" to musical instruments. What affects the sound the rubber bands make? What makes it hit a higher note? A lower note? Why? How is this like or unlike guitar strings and piano strings? (Interested students could research and report back to the class.)

Relate rubber band behavior to rubber balls (what kinds bounce better?) and air filled balls (relate stretchiness to bounciness).
When texts teach skills and concepts, they describe how to use it (and when and why), but the practice is drill: Perform this operation on, or apply this distinction to, the items below. (Of the sentences below, rewrite those that are run-ons. What is X percent of Y? Put your results in the form of a bar graph using the following headings.... Locate N on the map on page 63.) Even when students can produce the correct results and repeat the explanations, they don't necessarily understand the functions and purposes of the skills and concepts, and so fail to use or apply them spontaneously when appropriate.