8 Remodelling Science Lessons

Introduction

Understanding a critical approach to science education is often challenging, since many of us who teach science have ourselves been taught science in a "non-critical" way. Rather than tackle the critical approach to science education headlong, let us begin by understanding what a critical approach is *not*. Too often, science teaching places an overly-strong emphasis on a narrow mastery of the conventional explanations and techniques of established science. Sometimes this means asking students to memorize facts, definitions, diagrams, and so forth. More often, however, students are not required actually to memorize information, but they are asked to master a wide array of standard information and explanations, and they are asked to learn to solve a long list of standard problems or answer standard questions in the physical sciences, life science, or earth science. The emphasis in many textbooks is on preparing students to answer questions like the following, all of which are paraphrased from middle school science texts:

- What are the three kinds of volcanoes, and how are they formed?
- What is an element? a molecule? a compound?
- What are the three parts of a transformer? What kind of electricity does a transformer use?
- How are antibiotics produced? Do antibiotics cure all diseases?
- Which organ of the body pumps blood? The movement of blood is called _____.

While many of these questions represent information which might be of interest or of use to middle school students, mastery of this kind of information does not constitute the most powerful approach to science education. Teaching for a critical understanding of science involves additional elements. Let us go on and see what these elements are.

One of the very important goals of science education should be to help students understand how scientists establish their scientific beliefs. In other words, how do scientists establish the knowledge of the world which we want students to learn? By exploring this question, students

can come to a more fully-informed understanding of where the very involved and beautiful explanations of professional science have come from. They will begin to see that science does not arise in some impersonal way from experiments, but that human thought, in both logical and intuitive forms, plays as important a role as experimental data. In this way, they can see that scientific understanding is often powerful, but also fallible. Thus, they can become more critically aware "consumers" of the claims of science which we can read about in the newspapers every day. But perhaps even more importantly, students can be moved to an attitude of intellectual autonomy, the sense that they, too, can interpret their world through their own clear observation and critical thought. One attribute of critical thinkers is that they exercise independent thought and recognize that, at times, it is possible to come to an understanding of the world independent of authorities. Science education should combat the widespread belief that "It's someone else who does and understands science."

One important way to teach students about how scientists establish their knowledge is to allow students to investigate actual questions in the laboratory. Many typical texts, however, take all the initiative out of the "investigation" by presenting a detailed list of procedures to be followed, the steps to take in thinking about observations, even what students should observe and what they should conclude. To learn from a laboratory investigation or other kinds of inquiry activities, students should understand its purpose and should have some opportunity and responsibility to plan the approach and to interpret data or observations. Of course, teachers play an important role in student inquiry through their guidance and structuring, but it is possible to give students the responsibility of designing parts of investigations and interpreting their own data. Some of the remodelled lessons which follow point out ways to do this. In general, students can determine what data they need; design their own data tables; conduct experiments; think about their own interpretation of their data; and discuss their interpretations with classmates who might agree or disagree.

This is a key point in a critical approach to student inquiry: scientific thinking is not a matter of running through a set of steps called the "scientific method." Rather, it is a kind of thinking in which we move back and forth between questions, answers to those questions, and experiments which test those answers. "What do I think about this? If that's so, what will happen when I try ...? Why didn't this come out the way I expected?" In this process,we engage many of the attributes and skills of critical thinking. We must not make snap judgements; we must pose question clearly; we must see the implications of ideas clearly; we must listen as someone comes to a different interpretation of what we have observed.

In order to help students understand the basis for scientific knowledge, it is not enough to introduce them to something called "the scientific method," although science textbooks often devote a few pages to this topic. One of the problems with this approach is that there is no one method which all scientists follow. For instance, the work of a theoretical physicist who speculates about the fundamental nature of matter is different than that of the ornithologist trying to understand the behavior of birds. The physicist relies heavily on abstract mathematics, logical considerations, and even a sense of aesthetic judgment, while the ornithologist observes the natural environment very carefully and tries to find a pattern in his observations. So these two scientists use a very different set of "tools" in their work. Some scientists do experiments, but not all do. As an example, chemists can go into the lab and try a reaction in a variety of conditions; in this way they can test a theory about reactions. But evolutionary biologists cannot see what would have evolved if the situation had been different; they can only look at various kinds of evi-

dence left behind by what has already happened. So these two kinds of scientists must work in different ways, with one able to perform experiments in the laboratory and the other unable to experiment, but forced to rely on historical data.

Science is more than a way of thinking, however. Science includes a vast array of interlocking factual information, concepts and theories which provide us with one particular way of understanding ourselves and the world. In this introduction we will discuss two key features of a critical approach to teaching science content. First, that a critical understanding of science content emphasizes understanding of the fundamental ideas of science and their relationships rather than shallow understanding of lots of material. Second, that teaching for a deep understanding must include the recognition that students come to our classes with already well-established intuitive ideas about many areas of science.

The debate about coverage versus depth is an old one. While there may be reasons to emphasize a brief treatment of many science subjects, advocates of the critical approach to science teaching argue that students will understand science better and become better thinkers generally if they come to a deeper understanding of the central ideas of science. Since it takes time for students to grasp the implications of ideas and to see the connections between scientific concepts and explanations, we must spend more time on selected material. While it is beyond the scope of this introduction to outline the most important ideas in middle school science, we do encourage you to review your own teaching to assure yourself that you are providing students the time and experience they need to reach a deep understanding of the ideas central to the science you teach.

Our second point involves the preconceptions that students have concerning the science topics we teach. It is essential that science educators recognize that students of all ages have their own ideas about the world around us. From our earliest years on, we develop ideas about the growth of plants, the motions of pendulums, how birds can fly, and many more everyday experiences. These preconceptions play a very strong role when we teach for the deep understanding implied by a critical approach to science education. It is not enough to present the established knowledge of science. Every science teacher has experienced giving a clear and articulate explanation only to find, with a sinking feeling, that his or her students did not "get it." Jack Easley, the author of a series of penetrating articles on mathematics and science education, tries to explain this experience when he says, "cognitive research shows that young children develop and test alternative rational explanations which authoritative exposition can't displace."[1] A critical approach to science teaching recognizes that students must first articulate their own beliefs if they are to modify their beliefs in the light of their school experiences. Science teaching must begin by helping students to clarify and state their preconceptions so that they can go on to develop the deeper, more accurate understanding which is the goal of the critical approach to science education. Some of the remodelled lessons which follow suggest ways in which this might be accomplished.

[1] Jack Easley, "A Teacher Educator's Perspective on Students' and Teachers' Schemes: Or Teaching by Listening," Presented at the Conference on Thinking, Harvard Graduate School of Education, August, 1984, p. 1

Bugs' Bodies

Objectives of the Remodelled Plan

The students will:

- consider their preconceptions about insect anatomy while they build models of insects
- after learning more about insect anatomy, they will rebuild their models to incorporate their new understanding thereby examining, evaluating and modifying their assumptions

Standard Approach

In a brief discussion of insects, texts introduce the structures common to all insects. They name the three main parts of the body and give the number of legs, eyes, antennae.

Critique

Such brief text passages present some simple information about the structure of insects. They give us an opportunity to discuss techniques of science teaching which recognize that students have preconceptions about the subjects we teach.

It is important to remember that our students often have ideas about the subjects we are teaching. Students at this level will usually have some preconceptions about insects. They have ideas about what insects are and are not (most will not identify insects as animals), what they do, how they are built. Here are some important points to consider:

• Children do not come into our classes as "blank slates" ready to receive instruction. Rather, they often have well-developed, but somewhat incorrect, concepts already. These preconceptions strongly affect the understanding children come to when they learn science in school.

• Children's preconceptions are often interesting and creative ways to make sense of the various things children have themselves observed or have been told in or out of school. Children's preconceptions are not "learned" as a single idea, but are *constructed* in the child's mind as he or she actively tries to make sense of many experiences and pieces of information from both schooling and out-of-school experiences.

• Since these preconceptions often do "make sense" to some degree, especially in the child's viewpoint, it is difficult to change them. Often we as teachers think, "I said it clearly and correctly. Why didn't they get it?" We forget that children's' preconceptions are very resistant to change, and we often need to take an approach designed to help children modify the pre-conceptions they have already constructed.

Since children do come into our classes with their own preconceptions, how can we best teach science so that students form a more accurate and complete understanding of things? In teaching science concepts, we need to adopt a style of teaching somewhat different than we might use for other subject matter. The principles of effective didactic instruction, while sometimes useful when we are teaching information or well-defined skills, aren't the ticket here, because this par-

ticular model of instruction doesn't address two necessary features of good science teaching. In science teaching, we must first take into account students' *prior* knowledge and, second, we must shape instruction so that the students consider what they already know and then become actively involved in modifying their understanding to make it more complete and accurate.

In the lesson on bugs or any other science lesson, we should stress the connection between what the children are learning in school and their everyday experience. There are at least two important reasons for doing this. First, we all hope that school learning can help children understand their everyday lives; this should be one of the main goals of schooling. Often we try to use this connection to motivate our students to learn. But there is another reason to help students realize that they already have ideas about the science topics they are studying, and this idea is closely related to our discussion of students' preconceptions. Too often students seemingly compartmentalize their ideas into "school ideas" and "ideas about real life." In order for school science to help students make their views of the world more accurate and complete, we must break down the division between school ideas and real life ideas. Since much of good science instruction involves helping students refine their preconceptions, it is very important to set up situations which encourage students to look in their "real life compartment" for their existing ideas on the topics they are studying.

Strategies Used to Remodel

S-1 thinking independently
S-30 examining or evaluating assumptions

Remodelled Lesson Plan

Let's look at a lesson on bugs to understand how these ideas might work. While no single example can provide a complete illustration, this lesson on "How Bugs' Bodies Are Built" will give us an example. We should start our lesson with an activity designed to help the students recognize that they already have some ideas on bugs' bodies. While it might work just to have a discussion, there are better ways. In the case of our lesson on bugs, we could begin by having the students build models of bugs in "Mr. Potatohead" fashion. ***S-1*** In doing this, they must recognize and act on their preconceptions about how bugs' bodies are built. For instance, many students might think that bugs have eight legs, and their models would represent this.

After the class built their models (maybe even working in groups in order to share their individual preconceptions socially), the teacher would provide some information about bugs. This could take place in any number of ways, including all the traditional methods of instruction. The "principles of effective didactic instruction" provide helpful ideas for organizing these kinds of informational presentations. Then, following this direct instruction, the students would go back to their bug models, discuss with each other how real bugs differed from their model bugs and perhaps make a new version or modify the old one. By going back to the original model to make corrections, the students will confront their old ideas about bugs. In this active way, their preconceptions about how bugs bodies are built will be changed to be more accurate. ***S-30***

Scientific Reasoning: Do Snails See?

Objectives of the Remodelled Plan

The students will:

- clarify their preconceptions on the "sightedness" of snails
- clarify the key question by proposing experiments to provide evidence
- clarify, through discussion, that the interpretation of experiments involves assumptions

Standard Approach

In a brief discussion of mollusks, the garden snail is cited as an example ,and the statement is made that, "Attached to the body are two pairs of tentacles and a pair of eyes." More information about snails is then given.

Critique

Science texts often present a great amount of information without helping students understand why scientists hold this knowledge. This passage gives us the opportunity to discuss ways to help students understand how scientific knowledge is justified.

Science instruction in the life sciences, from which this example is drawn, often includes much information on the processes and physiology of cells and organisms. To some extent, this is appropriate. Too often, however, we forget that science education should include experience with the ways in which scientists establish their beliefs — in this case, about whether snails have eyes. As students grow in their ability to understand how scientific ideas are established, they will become more critically informed "consumers" of scientific knowledge and better able to distinguish well-grounded scientific belief from ill-grounded beliefs which pose as science. They will also develop the attitudes and skills needed to become intellectually more autonomous and able to come to their own understanding of the world based on personal experience and critical thought.

Strategies Used to Remodel

S-9 developing confidence in reason
S-24 practicing Socratic discussion: clarifying and questioning beliefs, theories, or perspectives
S-13 clarifying issues, conclusions, or beliefs
S-10 refining generalizations and avoiding oversimplifications

Remodelled Lesson Plan *S-9*

We might start this lesson with a discussion of snails and their behavior in order to expose students' preconceptions. "Do you believe snails can see? What makes you believe this?" Often, students will express a range of opinions on the "sightedness" of snails. Some reasons for holding their beliefs could be called "theoretical." For example, some students will say that all animals have eyes, therefore snails must have eyes. Others will say that those stalks on snails heads look like eyes so they must be eyes. Other students will have reasons for their beliefs which could be called "experimental" in the sense that they are based on observational evidence. Examples of this might be citing the fact that snails are active at night, when it is dark, so they must be able to tell light from dark. All these reasons provide a context for us to practice many of the critical thinking micro-skills, such as examining assumptions, examining evidence, and making plausible inferences through questions like the following: "Can you be sure they are eyes just because they look like eyes? Are you sure that all animals have eyes? Snails do come out at night, but that might be because it is cooler out. If that were so, could you still be sure that they were telling light from dark?" ***S-24***

After questioning students about their present beliefs and reasons, we could turn to experimental ways to explore these ideas. It would be ideal if students could actually observe snails as they tested their ideas, but discussion may be the only possibility. We could start by asking "What would be the difference in the snails' behavior if they could see or if they couldn't see?" ***S-13*** Perhaps a student would respond that snails would back away from a bright light. We could ask, "Would shining a flashlight at a snail and observing its behavior *prove* that the snail either could or couldn't see?" Depending on the particular responses which students made, you might suggest 1) that the light also is hot, and that might be what the snail sensed; 2) that the light might not be bright enough to affect snails; 3) that snails might *like* bright lights and might have moved toward the light. ***S-10*** While some of these possibilities seem a little farfetched, they do illustrate that experimental proof in science is complex and that the implications of an experiment depend on assumptions.

Discussions of this sort also give students practice in listening to the arguments of others. Through this kind of discussion, we can help students to critically examine how they, and scientists in general, might establish reasons for holding their beliefs. In this way, students can come to see scientific knowledge as the result of thought and evidence working together, and they will also begin to understand that evidence is *interpreted* in order to arrive at knowledge. Scientific knowledge does not arise unambiguously out of experiments.

The Air We Exhale

Objectives of the Remodelled Plan

The students will:

- interpret observations made after blowing air on a glass plate
- discuss the conclusions they can draw from their observations

Standard Approach

Texts state that body cells need oxygen and then briefly outline the movement of oxygen into the lungs and into the blood. They explain that waste substances from the cells enter the blood, move to the lungs and are then exhaled. Some texts suggest that students blow on a flat piece of glass and observe what they see. They are informed that there are small droplets of water. They are then asked where the water came from and are told that water is one of the waste materials from the body and that the air we exhale contains water vapor.

Critique

While texts try to provide some activities for students to perform, they tell students what they should observe and provide the "correct" interpretation. This approach may actually inhibit the students' sense of critical thinking by suggesting that, in school at least, questions are not really meant to be thought about.

Such lessons attempt to help students understand a very fundamental idea: that the air we breathe out is different in some way from the air we breathe in and that this difference has to do with what the body needs and the waste products it produces. The standard approach tries to base this assertion on some simple observations which students could make. However, several opportunities for engaging the students in critical thought are missed. Probably the most obvious opportunity is that when students have been directed to try a test for water vapor or for carbon dioxide, they are told immediately what they are supposed to observe. While there are obvious practical reasons for this approach, it does have the effect of undermining the student's sense of independence. Why should students try something for themselves if the texts tell them what they are supposed to observe? Or, if some students' observations do not agree with what the text tells them they will see, what should they think about this? Students either should be told what happens without having been asked a purely rhetorical question, or, better, they should actually try it for themselves. In this way, their intellectual independence is strengthened.

Blowing on a glass plate and interpreting what is seen presents several opportunities for developing critical thinking. The way texts use activities like this is a little problematic, since the implication is that the condensation on the plate provides evidence that water is a waste product

from the body. The text does not state this directly, but it also does not clarify what evidence this observation actually does provide. It would be difficult to provide evidence to students which proves that water is a waste product, but we could encourage them to think critically about the simple observations that are suggested by the text.

Furthermore, the reasoning and evidence are incomplete, encouraging students to make a poor inference. To conclude that the water comes from us, the air breathed out must be compared to the rest of the air in the room.

Strategies Used to Remodel

S-1 thinking independently
S-32 making plausible inferences, predictions, or interpretations
S-13 clarifying issues, conclusions, or beliefs

Remodelled Lesson Plan *S-1*

We could begin by asking students to breathe on a glass plate. Condensation will be visible if they observe quickly after breathing on the glass. The following questions will suggest a line of reasoning: "What do you observe? Have you observed anything like this before? What do you think it is?" The teacher can help students establish that this is water. "Is there water in the air around us? Where does the water come from?" ***S-32*** At this point, it would be helpful to establish that the water we observe on the glass is present in our breath but not in the air around us. "How could we test the air in the room to see if water will condense on the glass? ***S-13*** By fanning hard with your hand you can force air over the glass plate. What do you see now?" Through this line of reasoning, we hope to establish that our breath contains water vapor which the air in the room does not contain. "When we breathe on a glass plate, we see water condensed on the plate, but when we fan about the same amount of air over the plate, we don't see any condensation. From this, what can we say is different about the air we breathe out compared to the air in the room?" ***S-32*** Through this line of questioning, we are trying to establish that there is water in the air we exhale which will condense on a glass plate, while there is not enough water in the air around us to condense if we fan air over a plate. In this way, we illustrate to students the line of reasoning we must take to show that the air we exhale is different from the air we inhale. We have not yet shown that this difference is a waste product from our cells, but we can suggest this to students.

Simple Machines

Objectives of the Remodelled Plan

The students will:

- design a series of questions concerning simple machines which can be answered through the use of data which they can collect, thus thinking independently
- determine the information they need to answer their questions by clarifying them
- make measurements and record data
- provide answers to questions based on the logical use of their own data

Standard Approach

Typical lessons are designed to have students compare the effects simple machines have on the force required to move objects. In one such lesson, students are directed to copy a data table and then make several measurements. They are to 1) use a spring scale to lift a cart, 2) use a pulley to lift the cart and measure the force with the scale, 3) set up an incline and pull the cart up with the spring scale, thereby measuring the force needed, and 4) use the incline and pulley together and measure the force needed. They are then asked questions concerning the effects of pulleys and inclines on the force needed to move objects.

Critique

The main problem with such lessons, from the point of view of encouraging critical thinking, is that students are directed to perform a series of measurements *without* first conceiving a question or planning a strategy. The point of the activity unfolds only through the question in the "Conclusions" part of the activity, which is located at the end. The problem with this design is that students are asked to engage in a series of measurements which have no apparent relationship to any particular question. In addition, by asking students, as in the above mentioned lesson, to copy a particular data table (for which a model is given in the text), no chance is given for students to invent a way to organize the data they are about to gather. Again, this strategy removes another opportunity for students to organize their own approach to answering a question.

Both pulleys and inclined planes are simple machines with which 6th - 9th grade students may have had experience. Thus, this activity presents an opportunity for bringing out students' preconceptions. This could be done by asking students to name ways in which these simple machines are used in everyday life. Students should also be asked to predict and record their predictions concerning the effects of these simple machines *before* doing the actual measurements. Predicting the outcome of situations is an important way to bring students' prior knowledge into school activities.

Students should also be asked to give ways in which these simple machines are used in everyday life. While one effect of this kind of question is simply motivation, another important effect is drawing out students' *preconceptions* on these simple machines. Often students, mentally and unconsciously, separate their understanding into "in school" and "out of school" compartments. Thus it is important, in order to help students form a logically integrated understanding, to point out to them that they have already developed ideas on particular school subjects. These preconceptions form the basis for a better-developed understanding of simple machines, which we hope to encourage through activities such as this one on the effects of pulleys and levers.

Strategies Used to Remodel

S-1 thinking independently
S-13 clarifying issues, conclusions, or beliefs
S-33 evaluating evidence and alleged facts
S-5 developing intellectual humility and suspending judgment

Remodelled Lesson Plan

The most important aspect to remodelling this activity is to begin with questions for the students. "How do people use an inclined plane (or a pulley) to help them do something? What is it about an inclined plane (or pulley) that makes it useful?" ***S-1*** These kinds of questions lead naturally to asking students to design a way to measure how the force needed to hold the cart when it hangs vertically compares with the force needed to hold it on the incline. As part of this process, the students must clarify their questions so that they are answerable through use of the data they can compile. "What, exactly, are we trying to find out? How can we do so? What will that show?"***S-13*** In this way, the activity would be *designed by the students* rather than performed as a kind of "cookbook" activity from the text.

In the same vein, students should not be given a data table to copy; they should be asked to design ways to record their data so that they could make the comparisons in which they are interested. ***S-1*** Starting with a question rather than a list of directions requires students to generate their own procedures by clarifying possible questions and recognizing what kinds of data will allow them to give a reasoned answer to the questions posed. Why did we do this? What happened? What does that show? Could another explanation account for our findings?***S-33***

Asking students to make predictions is an important technique for bringing out their preconceptions. You might demonstrate weighing the cart directly and then, placing it on the incline, ask students "How much force do you predict it will take to hold this cart on the incline? How do you think the force to hold the cart will change if we make the ramp steeper?" You could also probe their theoretical understanding by asking "What is it about an inclined plane that makes it work this way?" ***S-1***

Having made predictions, the students must suspend their own preconceptions as they take data and logically analyze their data. Thus, they must suspend final judgement on the questions they have posed until they carefully evaluate the direct evidence they have collected. ***S-5***

Thinking critically involves the ability to reach sound conclusions based on observation and information. Critical thinkers distinguish their observations from their conclusions and situations from interpretations.

The Wave-Particle Theory of Light

Objectives of the Remodelled Plan

The students will:

- explore and clarify the nature of models and the use of model in science through discussion
- note significant similarities and differences between models and what they represent
- develop confidence in reason by proposing a model to explain a physical observation
- interpret an observation with light in terms of the wave model of light

Standard Approach

In introducing the electromagnetic spectrum, texts will mention the wave-particle theory of light. Students are told that if they look at a distant light source through a pinhole in a card, the pattern of light they observe is larger than the actual size of the pinhole. They are told that this "strange effect can be explained if light is thought of as a series of waves." They are then told that other kinds of experiments give different results. These experiments show that light always transfers energy in the form of small particles." The students are told that these light particles are called photons. The passage concludes by saying the *wave-particle theory of light* is the name of the theory that results from combining these two different kinds of experimental results.

Critique

This brief passage raises several questions: how models are used in science; why diffraction through a pinhole indicates that light acts like a wave; what "transfers energy in the form of small particles" means; what it means for light to act as a wave in some experiments and as a particle in others. Most of these issues cannot be dealt with successfully in a brief introductory passage. (In fact, such passages suggest considering whether these issues should be addressed this briefly if the result is to raise issues which students cannot understand.) It is possible, though, to help students understand the role of *models* in science and, for this reason, this remodelling discussion will focus on the use of models in science.

Strategies Used to Remodel

S-14 clarifying and analyzing the meanings of words or phrases
S-29 noting significant similarities and differences
S-9 developing confidence in reason
S-32 making plausible inferences, predictions, or interpretations

Remodelled Lesson Plan

The discussion could begin by raising the issue of models in general. The most familiar use of the word 'model' to students is probably as in 'model airplane,' a small representation of a larger object. The following questions will help students discover some features of models. "How is a model airplane like an actual airplane? How is it different? What does a model of an airplane enable you to do? What kinds of things does a real airplane do that a model cannot do?" Through these kinds of questions, we try to help students clarify their own thinking about this simple kind of model. ***S-14***

Next, we could introduce models which are more abstract than simple model airplanes. Most students have had experience with some kind of map, and we will use this to extend the idea of a model. After reminding the students about road maps, perhaps by showing them a road map of your state as an example, you could ask them to think of the ways in which this map is a model and how this map model differs from an airplane model. "Is the map a complete picture of your state? Could you use the map to find out everything you might want to know about your state?" These kinds of questions will help students understand that a map is a useful representation of some aspects of your state in which people might be interested. The map is not a complete, accurate representation of every aspect of your state, but it does help us understand and use the road system. We would probably make a different kind of map if we wanted to understand how the hills and mountains of the state worked to form river systems, for instance. The following kinds of questions will encourage students to explore the usefulness of maps. "What does this road map tell us? What does it help us do? Is this map a miniature model of our state? Are there things in our state which aren't shown on this map? Why are these things left off?" The point of these questions, and many other possible questions, is that maps (or models in general) are not complete representations but are designed to help us understand some particular aspect of the thing we are studying. ***S-29***

In the case of maps, we make a small model of a large object. In much of science we do the opposite — we make a large model of small things like atoms, for instance. But these models in science have many of the same features of the models and maps we have been discussing.

Sometimes in our science teaching, we can describe something or let students experience it directly and then ask students to invent some kind of model. For example, after watching a drop of ink slowly diffuse through a glass of water, students could try to invent the best model they can to explain what they saw. ***S-9***

In the case of a model for light, we can let students observe diffraction through a pinhole, as the original lesson points out. The students can also be shown pictures of water waves bending around objects — breakwaters in a harbor, for instance. You could ask, "If light acted like these kinds of waves, what would we expect to see when light travels through pinholes and into our eyes?" ***S-32***

Through questions like this, you can lead students to understand possible implications of the pinhole in the card activity mentioned in the original text passage. In this way we can begin to help students understand what it means to say "lights acts like a wave" or that "we can use a wave model of light."

The text goes on to mention the particle model for light. Unfortunately, the evidence leading to this model is much more difficult to observe and interpret. We cannot present this evidence to students. In this remodelling discussion, we have, however, seen an approach which helps students understand what models are and how they are used in science. We have also taken a brief look at some of the evidence which is best interpreted thorough the wave model of light.

Your first remodels should use those skills or insights clearest to you. Other principles can be integrated as they become clear.

Newton's Second Law of Motion

Objectives of the Remodelled Plan

The students will:

- make plausible predictions about motions of objects
- analyze their experiences regarding motions of objects
- clarify the concepts of force, friction, and mass through discussions and questions about common experiences

Standard Approach

Texts often approach teaching Newton's Second Law of Motion by using examples of frictionless surfaces, such as a hockey puck on ice. They then state that experiments in such situations have shown that doubling the force will double the acceleration. Some texts introduce the mass of an object as the ratio between the force and acceleration, and provide a summary of Newton's Second Law: "When a force is applied to an object, the object accelerates in the direction of the applied force. The acceleration is greater when the force is greater. The acceleration is less when the mass of the object is greater."

Critique

Newton's Second Law is very difficult for students to understand, since it apparently contradicts many of our everyday experiences. For instance, frictional forces are so much a part of everyday life that students rarely have the opportunity to experience frictionless motions. The text misses an important opportunity for students to come to terms with this aspect of their experiences. Also, the definition of 'mass' as force divided by acceleration is much too abstract to be of use to students at this level.

This lesson gives us the chance to raise the question of the *appropriateness* of presenting particular science concepts to 6th -9th grade students. It is appropriate for these students to try to understand the motion of objects in terms of their own experience and in terms of the ideas of scientists who have studied motion. Newton's Laws, though, present a highly abstract and condensed way of understanding motion. Many of the important aspects of Newton's Laws are often not apparent in everyday life, and therefore, students' preconceptions about motion are often quite at odds with the abstractions of Newton's Laws. Briefly, what are some of the preconceptions students have which apparently contradict Newton's Laws?

The First Law states, "Objects move in a straight line at constant speed unless a force is acting on them." Since everyday motions are always subject to forces, especially frictional forces, children are without the kinds of experience which would enable them to have "experienced" the First Law. As a different example, many middle school and older students think that if a stone

whirled overhead in a circle on a string is released, the stone will follow a kind of curved path (when viewed from above). Their preconceptions on this kind of motion are entirely at odds with the prediction of the First Law that the stone will follow a straight line.

The Second Law deals with the relationship between force, *mass*, and *acceleration*. Again, this presents difficulty for students, since our everyday experience leads us to see motions in terms of force, *weight*, and *speed*. Based on everyday experience, most students believe that the harder you push something, the faster it goes. We develop these preconceptions from experiences like pushing heavy objects across the floor. While the confusion of weight for mass is not a relatively important issue for middle school students, the spirit of the Second Law is lost when we relate forces to *speeds* rather than to *accelerations*.

Strategies Used to Remodel

S-12 developing one's perspective: creating or exploring beliefs, arguments, or theories
S-1 thinking independently
S-14 clarifying and analyzing the meanings of words or phrases

Remodelled Lesson Plan *S-12*

We begin remodelling this lesson by changing its goal somewhat. Instead of trying to teach Newton's Laws, we try to do two things: 1) we try to help students articulate their preconceptions about the motion of objects; and 2) we try to challenge students in a way which encourages them to modify their understanding to arrive at a more powerful, all-encompassing view of their experiences, thus developing their perspectives. If we can accomplish these goals, we will help prepare them for a critical understanding of the abstract statement of Newton's Laws later in their education.

As an example, let us begin with the relationship between force ("pushes and pulls" to students) and motion. We could have students consider two extreme situations: pushing a car along a road and pushing an object over a very smooth, frictionless surface. (Use a situation your students might have experienced like a frozen lake, an air hockey table, sliding on a smooth or wet floor, etc.) "What happens when we stop pushing? Why?" ***S-1*** Through questions like this, we are trying to challenge one characteristic preconception which is that something moving requires a continuing force. Our strategy is to cause students to consider the difference between high-friction and low-friction situations. Also have them consider the force required 1) to *stop* moving objects, and 2) to change their direction. Through this strategy, we hope that students will see changing motion (in speed or direction) as the result of external force acting on the object. This is one of the difficult points in Newton's Laws for beginners.

Another major point in Newton's Second Law is the mass of an object. While the texts' definition of mass as "the ratio of force to acceleration" is technically correct, it is not an appropriate definition for students at this level. At this age, students should learn science by considering concrete ideas. While force and, to some extent, acceleration are concepts with which students have direct experi-

ence, the idea of a *ratio* of these quantities is too abstract for students to understand in a critical sense. It is probably better to refer to the mass of an object as "the amount of matter." Students often confuse the *mass* of an object with the *frictional force* associated with moving it. Big objects, like pianos, are difficult to move around due to friction. It is, however, surprisingly easy to move a small boat weighing about as much as a piano, since the frictional force opposing the motion of a boat in the water is very small. Through questions involving large objects and small objects, along with high- and low-friction situations, we can clarify students' understanding of mass of objects. ***S-14***

Ask students, "Why is it harder to move objects on rough surfaces than smooth or slippery surfaces? Why is it harder to start an object moving on a smooth surface, than it is to *keep* it moving? Why is it harder to stop a bulky object than one with less matter? A faster object than a slower one?"***S-1***

Macro-practice is almost always more important than micro-drill. We need to be continually vigilant against the misguided tendency to fragment, atomize, mechanize, and proceduralize thinking.