✦✦ Chapter 38

Critical Thinking and Science

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Abstract

In this brief paper, originally published as a chapter in the Critical Thinking Handbook 4th–6th Grades, *Paul and Binker discuss the key features of education in science. They argue for the need to teach students to think scientifically and to examine and critique their preconceptions of science and the physical world. They then point out common flaws in standard instructional practices, and provide generic questions students can consider when studying science.*

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 do organize and internalize facts, learn terminology, and use scientific procedures. But they learn them deeply, tied into ideas 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 the student does not usually affect those 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 knowledge. 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 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 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."[1] This student's response graphically illustrates one way students can retain their own beliefs while simply juxtaposing 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 what they learn, a process essential for genuine understanding.

> 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.[2]

Science texts suffer from serious flaws which give students false and misleading ideas about science. Scientists are not given experiments; they begin with a problem or question, and have to figure out, through trial and error, how to solve it. Typical science texts, however, present the student with the finished products of science. These texts present information, and tell students how to conduct experiments. They have students sort things into given 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 practice or 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 science concepts that have another meaning in ordinary language (e.g. 'work') are not distinguished in a way that highlights how purpose affects use of language. Students need to see that the 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. "How do scientists get from *that* observation to *that* conclusion?" Sometimes the experiment or study is not obviously related to the question it's supposed to answer. 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. Scientific thinking is not a matter of running through a set of steps once. 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?

Furthermore, 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.

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 science is much more monological than social studies, students should learn to do their own thinking about scientific questions from the beginning. 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 other 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.

Students often mindlessly do their science work. We should look for opportunities that call upon them 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 experiments? (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?

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, help students learn how to state their own assumptions and to recognize the assumptions of others.

✦ *Footnotes*

1 Hugh Helm & Joseph D. Novak, "A Framework for Conceptual Change with Special Reference to Misconceptions," *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*, Cornell University, Ithaca, NY, June 20–22, 1983, p. 3.

2 Jack Easley, "A Teacher Educator's Perspective on Students' and Teachers' Schemes: Or Teaching by Listening," *Proceedings of the Conference on Thinking, Harvard Graduate School of Education*, August, 1984, p. 8.