Rethinking the Way We Teach Science

The Interplay of Content, Pedagogy, and the Nature of Science

Louis B. Rosenblatt

ROUTLEDGE

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Rethinking the Way We Teach Science

Offering a fresh take on inquiry, informal and readable, this book draws on current research in science education, literacy, and educational psychology, as well as the history and philosophy of science, to make its case for transforming the way science is taught. It addresses major themes in national reform documents and movements—themes teachers are keenly aware of in their day to day work: how to place students at the center of what happens in the classroom; how to shift the focus from giving answers to building arguments; how to move beyond narrow disciplinary boundaries to integrated explorations of ideas and issues that connect directly with students; and most especially, the importance of engaging students in discussions of an interactive and explanatory character.

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- Provides a much needed foundation for STEM and interdisciplinary study as ways to deeply transform how science is taught
- Shows how teachers might teach a wide range of science topics from elementary school through high school—is relevant across grade levels and subject matter
- Is highly interactive—in keeping with the pedagogical argument at its core about the value of talk and dialogue

The premise of this book, with its sense of humor and of pathos and its passion for the promise of good schools, is this: If teachers work at having things make sense, students will join them in that work. But this is complicated: Teachers will find themselves in the intersection of three conversations, the interplay of science content, the teaching of science, and the nature of science; they will also need to consider their students, who are often alienated and uncertain of their place in school or society. As the book addresses these issues, it is, above all, about choosing to place the authority of reason over that of right answers.

Lou Rosenblatt is a teacher with over 30 years of experience, chiefly at The Park School, but also at The Baltimore Freedom Academy, Johns Hopkins University, The University of Leeds, and Gallaudet College. He is a consultant with TIES, having worked chiefly with Baltimore City Public Schools and STEM schools in North Carolina. He has published several articles and presented at numerous conferences, and he was a member of the design team which secured funding from the Bill and Melinda Gates Foundation among others to establish The Baltimore Freedom Academy.

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Preface

Statement of Intent

Not too long ago I attended a meeting where a publisher's representative was urging the adoption of a series of textbooks. After 10 or 15 minutes of describing various advantages of the books, he came to a new feature. Teachers could access a web-site where lesson plans were available. One needed only to specify the number of days to be spent on a given chapter, and out would come a breakdown for lessons: 5 minutes here, 10 for this activity, and another 15 for that . . . In addition, each specified chunk of time would be related to state learning objectives and national education standards. I could feel the energy in the room. Clearly, the teachers were pleased by the notion of a web-site that would virtually write their lesson plans. But there was more. The sales representative went on to say that these lesson plans were especially good for new teachers, who have a tendency "to get bogged down explaining things." That was the part I loved. Here was help making sure you wouldn't waste your time explaining things.

It is my intent here to praise the virtues of getting bogged down. There is more here than a question of speed. Choosing to go "slowly," that is, choosing to stop for questions, to explore what it all means, and to lay out a map, is also choosing to have things make sense. In the end, it is placing the authority of reason over that of right answers.

Everything in the chapters that follow comes down to this: if we work to have things make sense, students will join us in that work. But it is complicated. We will find ourselves in the intersection of three conversations. There is the science we seek to teach, such as the material in our textbooks. There is, as well, a body of pedagogical notions about how best to go about teaching. To these we may add the history and philosophy of the sciences, which help us appreciate both the nature of science and the problems and issues that shaped the modern understanding. Together these three make a good story.

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Chapter 1

On Wonder

Some time ago Jesse, a kindergarten child, and I were scurrying through a heavy rain on the way from my car to his classroom. I remarked that it had been raining pretty heavily for some time and over a large area. That was a lot of water and it must be very heavy. Had he ever lifted a bucket of water? Yes, he had, and it was really heavy. So what did he think about how all this water could stay up in the sky? By this time we had entered the building and he looked at me and proceeded to explain that there was a great big glass or plastic ceiling in the sky. Moreover, that's what thunder was—when it would crack. This was a wonderful theory, and I said so; but it occurred to me that he had recently flown for the first time. Did he think the plane had broken through the glass barrier? He didn't say anything at first . . . you could see him thinking about things, and of course the most striking feature of flying is looking down on the clouds. Then he said that he hadn't thought of that. Maybe his idea wasn't right. Maybe something else held the water up. "Wonder what it is," he said. "Yes," I agreed, "wonder what it is."

When Jesse had paused before he went off to join his kindergarten class, when he paused to say "Wonder what it is," the wonder he expressed was not so much a wonder of nature as a wonder of the human imagination. It was not the rain he was wondering about, but the intricacy in thinking through how it might work. This is an important distinction. Often people take science to be about nature's wonders, but it isn't. Science is not a series of National Geographic specials on volcanoes or the fantastic world within a microscope or the birth of stars. It's how we understand these things.

Of course, in seeking to understand nature we need some experience, but too often science class becomes a time to marvel at the world when it ought to be a time to marvel at reason and the power of the imagination.

There's a lovely story about the connection between reason and the imagination that comes from the latter years of the eighteenth century and seems exactly right here. James Hutton, a Scottish man of science, had proposed that we link the hard, crystalline rocks so abundant in the Earth's crust, rocks like granite and marble, to volcanoes and fires deep within the Earth. This was a remarkable hypothesis. The only rocks clearly derived from volcanoes are rocks like pumice, rocks that are porous and brittle with a dull, matte-like finish—utterly different from the granites and marbles Hutton proposed also came from volcanoes.

Hutton ably made his case and deeply transformed the way we understood the Earth's history. Before Hutton, the story of the Earth was the modest tale of a gradual wearing down, as the wind and elements eroded its bolder features. With Hutton, things opened up dramatically. Different parts of the Earth could be different ages, depending on the play of igneous forces. Whole mountain ranges and continents could be relatively old or young. The Rockies, for example, are only about 40 million years old; while the Appalachians are around 300 million years old. Moreover, in a given place the layers of rock may reveal a history of the rise and fall of landscapes as complicated as the rise and fall of the kings and queens of medieval Europe. This was immediately clear to Hutton and his colleagues on a trip into the field when they came to Siccar Point, which juts out into the North Sea some 30 miles east of Edinburgh. There they found two beds of sedimentary rock, each one representing a long stretch of time when this region had been below sea-level so that sediment could accumulate and compact into rock. Furthermore, the fact that the lower, older bed was vertically standing meant that it had been upended from its original horizontal lie by powerful forces long before the younger bed had been formed above. Here is a lovely photo of Siccar Point from the geology department of Lawrence University in Wisconsin.

Figure 1.1 Siccar Point. By permission of the geology department of Lawrence University.

Reconstructing the likely sequence of events that had produced this vista—two separate events of uplift and vast spans of time for erosion and the accumulation of sedimentary rock—John Playfair, one of the group wrote: “The mind seemed to grow giddy by looking so far into the abyss of time, . . .” and then he added “we became sensible how much farther reason may sometimes go than imagination can venture to follow” (Playfair, 1822, vol. 4, p. 81). When we marvel at the intricacies of the world of electron-microscopy or at the vastness of distant nebulae “dying in a corner of the sky,” we are carried to these fantastic worlds, not by the imagination of the poet, but by the careful reasoning of the scientist making sense of the world.

“Excuse me, but don’t you have that upside down? Everyone knows that poets are imaginative and carry you to exotic places like Xanadu; while careful reasoning only gives you whatever fantasy you can find in the fine print of a footnote.”

“Oh, hello. I know what you are talking about, but if you stop to consider the proportions of modern science from black holes to the ‘charm’ of quarks, isn’t it clear that reason sometimes goes far beyond footnotes or Xanadu?”

“You make science out to be a something like the *Twilight Zone*. But isn’t it all about the facts? What about careful observation and the scientific method, meter sticks and triple-beam balances?”

“Facts and observation are there, but they’re a small part of things. There are always two stories to tell. There’s the one that features the thing itself. You know, the ‘Wonders of Nature’—from the intricate lace-like patterns of snowflakes to the dramatic images of nebulae billions of light years away. These are the stories we find on public television specials. They’re great, but there is another kind of story. It’s the one we invent in order to understand. It’s the one with all those wonderful notions about things we can’t even see—such as atoms, the double spiral of the DNA molecule, evolution . . .”

“Whoa! Do you mean atoms and evolution were just made up?”

“Certainly! Evolution is far too slow to see, and atoms are far too small for us to experience. You can’t pick one up, hold it to the light to see what color it is, or place it on a scale to weigh it. The atom was invented, not discovered. The key here is a matter of how we see things. Let me tell you a story . . .

“Some time ago I went hunting for dinosaurs. As I went, I remembered the *Golden Book of Big Dinosaurs* I’d read as a kid: their monstrous size, the violence of their eyes, their fierce step, and their great jaws. It was a completely foreign and exotic world. Yet, it was also a *real* world. Perhaps this is the key to their mystique; here were dragons that actually stomped about and breathed their fiery breaths. That’s why you get all those marvelous tales, such as Michael Crichton’s *Jurassic Park* (1990), where hidden away in lost corners of the globe are descendants of the lumbering beasts of the Mesozoic. We are captivated by the thought that they were real.

“On my expedition, we went back to the mid-Jurassic, to the Morrison formation—rocks of a characteristic type deposited 150 million years ago but presently found all around you, if you happen to be in parts of Colorado and elsewhere. We can all conjure up the lost world of the dinosaur. A typical scene might involve great beasts lumbering through swamps, or locked in deadly combat, and of course, there are volcanoes smoldering in the background (this is the cover illustration by Joel Snyder of David Eastman's *Now I Know: Story of Dinosaurs*, 1982).

"What an extraordinary contrast this is with the modern scene, the one that shows a barren and bleak hillside, no volcanoes, no swamps. We had gone to

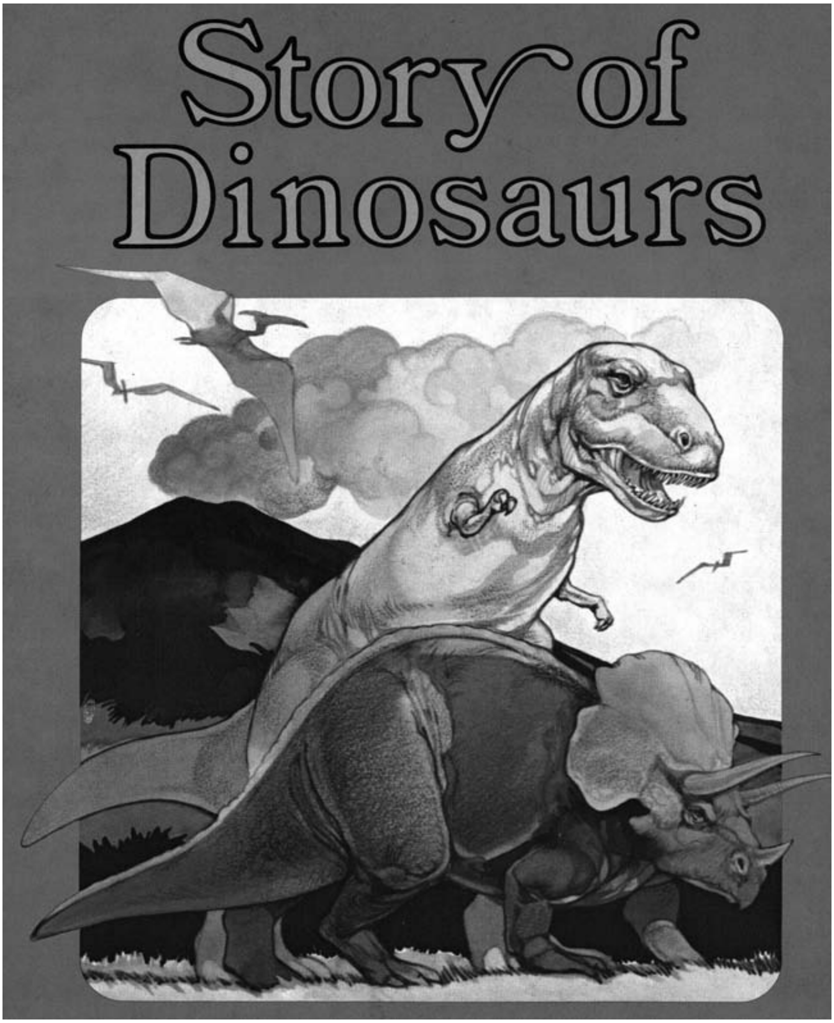

Figure 1.2 Now I Know: Story of Dinosaurs by David Eastman. Cover illustration by Joel Snyder. By permission of Scholastic Inc.

Figure 1.3 Dinosaur fossil site in Colorado. Author's photograph.

a site near Grand Junction, Colorado, in the Western range of the Rocky Mountains, not very far from the Utah border, a most prosaic patch of arid land.

"If you could superimpose these two scenes, you would have the measure of the difference between facts and theories. Here we are, reason tells us, knee-deep in the world of the Iguanodon and the Apatosaurus, with Pterodactyls in the skies, flanked by Tyrannosaurus Rex in battle with a Triceratops, the great plebeian warrior. Giant ferns grow around us, while volcanoes are smoldering, and what do we see? What are the facts? A bleak, bleached out hillside!

"At a certain point in our scouring of the hillside, I realized that everyone else had found a fossilized morsel to relish, and that all I had been able to do is swat at the predatory gnats that are a large part of the modern environment. Determined not to let the moment escape, I opted for the beaten path and began to search for some sign of ancient life in the rocks just a few feet to the right of another find.

"I clambered along the slope, chose my spot a respectful distance away, and began to scrape at the surface. Success! I found two small lumps of dark rock! I called out to my friend, a paleontologist, and he came over right away. 'Ah,' he said, 'a great find. It looks like two vertebrae of a Camarasaurus.' I had done it! I had found the remains of a dinosaur. The Camarasaurus was a beast of that broad, sleek Apatosaurus design, though quite a bit smaller. Its remains are not uncommon in the Morrison, and there are some lovely specimens on display at Dinosaur National Monument not too far away in Vernal, Utah.

"Then, right at the height of my joy over my great discovery I learned we had to go. I was shattered. One of our party was, unfortunately, quite ill, and ought not to have gone out in the first place. And so everyone packed up their goods and made for the car and the ride back to town. I was left standing there in a daze, staring at my two lumps of dark rock; since that was all they were. I wasn't going to have the chance to bring them to life. The reality they constituted would continue to be a private affair between them and their setting. I hadn't found vertebrae, I'd found two dark rocks. To make them the vertebrae that they really were would require work, and that's the moral of the story. All we experience is the appearance of things. The real world takes time and work and analysis and a well-schooled, disciplined, imagination. But I was already lagging behind. So I too picked up my gear and headed back toward the car."

"That's really a drag, but I think I see what you mean by the difference between what we see with our eyes and what we see with our understanding."

"No problem . . . I'll just carry on."

There are wonders to nature, such as the Grand Canyon or the Great Barrier Reef, where we are overwhelmed by nature's colors and proportions. But there are other wonders, such as black holes, ice ages, and the intricacies of molecular genetics, where the color and proportions rest in our reason, in our capacity to conjure up what things must be like in keeping with argument and analysis. Without the reasoned imagination Playfair spoke of, our world would be bleak and bleached out.

Years ago, T.H. Huxley suggested that, for most of us, the world is like walking through an art gallery where most of the paintings have been turned to the wall (Huxley, 1907, #80). We lack the feel, the insight that can evoke the wealth all around us. That is what expertise is all about. I had a colleague who had grown up on a farm. He told of watching his father pick up the soil and work it in his fingers, and from that his father could tell what fertilizer to add. Any such expertise will turn some of Huxley's paintings around, but I readily confess . . . the capacity to see the abyss of time, or to know those rocks as vertebrae, that would be especially sweet.

The sciences are filled to the brim with notions like "the Earth is a planet" or that "life has evolved"—notions invented in order to explain phenomena such as those two dark rocks on that bleached out hillside in Colorado. But these ideas are far from obvious. Presented outside the context of the puzzles that prompted them and without the support of the arguments that carry them, these ideas lose their vitality. We don't know what we are looking at and we don't know what the theories are really telling us. Science becomes at once inert and exotic, like a display case of butterflies or tropical birds. There remains nature's artfulness, its design, its color, but we miss the life within. We miss the movement reason provides, the argument that would have coursed through the veins, as it were. And so we are left with landscapes that do not present the "abyss of time." We are left with dark rocks, instead of the vertebrae of dinosaurs. Our task, as teachers, then is straightforward. It is to connect answers to puzzles, theory to experience. It is to see the wonder of reason's imagination, to see the argument—and, of course, to share that with our students.

If this were a class or a text in geology or evolutionary biology, this story might lead to an examination of what it takes to see vertebrae where the untutored eye sees only dark rocks. We might examine comparative anatomy—the contours of different bones and how their contours are related to their function—and we might talk about the processes of fossilization. But our focus is quite different. When we ask "What is the significance of the difference between rock and vertebra?", what we are really seeking is the difference between the body's eye and the mind's eye, the difference between what I see and what my understanding can "see." For us, in an essay on the practice of science teaching, we want to know how this should shape what we do in the classroom. How should we talk, so that students see both the two dark rocks *and* how they are vertebrae?

On Talk

We have talked ourselves out of talk. We have seen this already in that publishing representative's remarkable observation that their web-site would help teachers avoid getting bogged down explaining things. We can see it as well in "direct instruction," an approach to teaching that is virtually scripted. As the National Institute for Direct Instruction says on its web-site: "The popular valuing of teacher creativity and autonomy as high priorities must give way to a willingness to follow certain carefully prescribed instructional practices" ("About Direct Instruction (DI)," n.d., www.nifdi.org/15/about-di).

This is not to say there are not a lot of words. There are lots of words in our science programs. Too many. In a delightful paper, Robert Yager (1983) counted the number of technical terms introduced in our science textbooks. There were literally hundreds and thousands more words than the standards set in foreign language study. But these words are answers, and answers are not talk.

This is an interesting distinction. Why would we make it? In an intriguing book, *A is for Ox*, Barry Sanders talks about the importance of story-telling. Children learn by talking. The very sense we have of ourselves as persons, he suggests, is a "sounding or telling through," a *per-sonare* (Sanders, 1994, pp. 45–46). This notion of talk as story-telling is the key. We forge our identity, our person-hood, through the act of telling stories.

What is true of the child is also true of the student. As children shape their sense of self through talking as story, so students shape their identities as reasoning beings through the act of explaining. They forge their intellects by giving shape to arguments. Where a child learns the role of suspense and detail in focusing a tale, so the student learns the role of issues and evidence in focusing an explanation. In both the development of the child's talk into conversation and story-telling and the student's development of explanatory schemes from his or her earliest "essays" to fuller expositions, the individual draws upon their inner self and in the act of drawing . . . gives shape. Consider the name we give to the kind of writing where students explain themselves: "expository writing." The act of explanation is to expose, to reveal, to lay open, *and* at the same time it is to stand out from—to *ex-pose*. That is the great power of making sense of things. It is simultaneously the laying open of what was hidden, and the assertion of self—the standing out from shelter. When we explain, we expose and we are exposed.

Language is a curious thing. A rose by any other name would smell as sweet; yet, there is something to the way we name things. There is something, for example, about naming explanatory essays as "expository" writing that captures the heightened vulnerability of trying to explain yourself. This is underlined when we stop to note that an "essay" is an attempt, an undertaking, and only in the modern era has it come to mean a written piece. There is an essential vulnerability to being a student.

Several years ago I attended a small high school graduation party for the first born child of a family that had immigrated to the United States from Iran. As the father proudly spoke of his daughter's success, he found himself talking with bitterness about a teacher he had had who had not given him the credit that was his due. Such is the pain we suffer as students at the hands of adults through their indifference, their failure to recognize what we have done, that decades later that pain is still with us. Here was vulnerability writ large.

To continue the discussion about the value of talk, how different this talk is from sharing information. Too often we tell students. Too often we make the serious business of the classroom a kind of decanting where we pour information, however elegantly, into their minds. Over the years, I have had many colleagues. Several have stumbled over just this distinction between talk and information. They could see that class was "flat," that students were not really enjoying class or activities, but they couldn't see what the real problem was. One colleague—very bright, with a strong background—kept revising his presentations, his lectures, convinced that if he could just find the right way to organize the material, students would see what was going on, would do well on tests, and would be happy about their learning. But students only became more disenchanted. They hadn't needed a still more elegant essay, a still more refined answer. They needed questions to ponder, seeming contradictions to resolve, and issues to engage and make sense of.

Another colleague often stayed late working and reworking labs for his classes. I'd ask him what he was up to and in the course of his account it became clear to me that he was doing the best part of the lab. He was solving the problem, finding a way to make something work to prove a point. All that was left to the students was to turn some stuff on and collect the data. He needed to hold students responsible for how they could make sense of a puzzle or address a problem. Only when we do this are we nurturing their capacity to reason and so become more fully independently minded—just as story-telling nurtures a fuller sense of identity.

On Perplexity

The importance of talk in the classroom is heightened once we appreciate that the material does not speak for itself. Our textbooks present the material as if what it means and why we would hold these views is obvious; but it is no more obvious than was the claim that those two rocks were vertebrae. I have been there. We have all been there. The material does not speak for itself.

If this is so, then how can we speak for the material? How can we focus the mind's eye of a class full of students, so that they are prepared to see the vertebrae in the rocks? This is a central issue as we prepare for the classroom, and it proves to have many parts; but right in the middle is the notion of perplexity.

Perplexity is the natural companion to that sense of wonder linked to the imagination. When Jesse wondered what held the water up, he was perplexed. Things did not make sense. There is an interesting nuance here. Not all things that don't make sense are perplexing. Perplexity seems really only to apply to those things that we think we ought to understand. So, the classic Norman Rockwell-like image of a father scratching his head while standing in front of the various parts of a bicycle that he's been trying to put together is an apt image of perplexity. On the other hand, the fact that the same father might not know the sequence of nuclear reactions involved in the release of the vast energies of stars is more simply something he does not know. This difference is crucial for the classroom; for perplexity is vital, it enlivens, while information is inert and deadening. If we return to Sanders for a moment, the importance of talk highlights the corrosive impact of television and other modern forms of passive entertainment. Children are being stimulated, but not challenged. Their time is occupied, but their imagination, their own talk and thus their own forging of notions, is not. He offers this striking observation: "Young children need to feel lost, confused, and bewildered enough to concoct their own stories in order to climb out of tight situations. They need to string together narrative threads from here and there to reach meaning in their lives" (Sanders, 1994, p. 47).

As with the development of children, so too with the development of students. The logic of the material, as opposed to the logic of the exchange in a classroom, tends to foster a passive witnessing. Students do not expose. That is the work of the text and the teacher. The material does not provoke. It lies there, inert. The task is not to forge an understanding but to secure identification. Students witness. They watch. And even the various hands-on activities we offer are programmed, formatted to provide a witnessing, a confirmation of the material. There is no driving perplexity.

There is a lovely display of the pedagogy of perplexity in a text as old as they come. Over 2,000 years ago a young Athenian, Plato, established the first recognizable school in the Western tradition. The textbooks at this first school, the Academy, were dialogues he had written that caught the wisdom of his mentor, Socrates. Several of these dialogues are still often read in university study, and the reason is clear. Plato and Socrates systematically examined the most fundamental questions. In the dialogue, *Meno*, for example, the opening line has the character, Meno, asking: Can virtue be taught? Certainly, this is a key issue.

In the course of the dialogue, Socrates' persistent questioning irritates Meno. He compares Socrates to a stingray; for whenever anyone comes into contact with a stingray, they are numbed by it. And that is just what Socrates' questioning has done. It has reduced him to a state of numbing perplexity where he now questions what he had, just moments before, confidently assumed he knew. Socrates acknowledges that there is a certain justice to this charge; for, being perplexed himself, he infects others with his perplexity. Yet, he argues, it is for a noble and just end, as true opinions are aroused by questioning and turned into knowledge (Plato, 1956, 80d).

As we have already talked about the meaning of "expository," perhaps we can venture another such note. Consider the word "perplexity." *Plexus* meant "knot" in ancient Greek and *per* meant "through," so that we might think of a perplexity as being knotted all through, confused by the issues and choices. Socrates would create perplexities by adding ideas and arguments to think about.

The moral then is this: we need to perplex our students, to engage them with a puzzle that strikes them as puzzling. When Socrates first speaks to Meno about virtue, he encourages him to explain his ideas: "What do you think virtue is?" He then takes what Meno offers very seriously. Will this notion do? He finds that it will not. There is now clearly a problem, and the real work may begin. Further notions are offered and carefully considered. What we gain from this as an approach to the classroom is that learning begins with a puzzle, a perplexity—something that doesn't fit—and so, from the beginning, there is more going on than a witnessing. There is a problem to be solved. Perplexity focuses the mind's eye.

This, then, is our first step. In terms of the practice of science teaching we have suggested an orientation. When we walk into the classroom we need a problem . . .

"Excuse me again. I have another question."

"That's fine, but I can see that this is going to be confusing. That is, if you are going to do this very often . . ."

"Well, I don't know, of course, but . . ."

"O.K., let me see . . . we could put this in *italics. That should help; so would names. What should we call ourselves?*"

"You're the writer. We could call you that, and then I would be the reader."

"Yes, that would be fine; though, of course, you're not really a reader. You're more a projected reader, a kind of hypothetical entity."

"What! You mean I don't really exist?"

"No, not exactly. You're more or less an imaginary friend."

"Well, that's not so bad. I'm an imaginary sidekick; so, you may call me Sancho."

"Fair enough, Sancho. Did you have a question?"

"Yes, D.Q., it's that I don't understand how you can start with a problem. Don't problems come at the back of the chapter? How can you start with them?"

"There's a pretty fundamental difference between problems at the beginning and problems at the end of a chapter. To start with a problem is to invite a conversation: as in 'Can virtue be taught?' To end with a problem is to say, in effect, 'You are being held accountable for the following.'"

"Yes, but it's still not clear to me how you can start with a problem. Problems presuppose knowing something and there being issues with it. The material comes first."

"Perhaps, but I tend to see it the other way around, Sancho. The material in the chapter is a set of answers . . . answers to questions that are not made explicit most of the time. This was the argument put forward by an intriguing character, R.G. Collingwood, about a hundred years ago. For Collingwood, the act of understanding was directly tied to figuring out the question a person is answering as they write or say something. He came to this out of an interest in archaeology where he found himself routinely looking at artifacts and asking what problem they had been designed to solve. Only by knowing what it had been for could you understand what it was and with that, what life had been about for these ancient peoples (Collingwood, 1939, pp. 29–39).

"There's a charming book, Motel of the Mysteries, *by David Macaulay (1979) that plays with this. Do you know it?"*

"No, I don't, D.Q."

"The story is set far in the future after our civilization has collapsed. Future archaeologists stumble upon the ruins of a motel and attempt to decipher its meaning. They see it as an elaborate burial chamber, as they found a body on a ceremonial platform (a bed) facing the great altar (a television). Another body was found in an inner chamber (the bathroom) with a still more elaborate, polished white sarcophagus (a bathtub). The opportunities for misunderstanding are staggering and in this case amusing. The point for Collingwood is that we do this all of the time. Early on we develop a mental faculty where we construct what is on someone's mind by trying to put ourselves in their shoes, as it were. We ask ourselves: what would it mean if I were to act or say these things?

"Years ago I had a curious conversation with my son. He had just turned four and, as I tucked him into bed for the night, I said that he was old enough now so that in a few months he would be able to start at the Park School, where I was a teacher. After a lengthy pause, he told me that he liked being four. Somewhat

taken aback, I said I was happy he enjoyed the prospect of being four and I was sure he would like being five and six and so on.

"Something was up, but I would not figure it out until several months later when Pete spent a day at Park. We picked him up at the end of the day and he had this big grin on his face. 'They have little kids!' he exclaimed. You see, I taught in the high school, and Pete must have assumed that when I said he could go to Park that I meant he would go to the high school. A little concerned about his father's judgement, he had offered the simple observation that he liked being four. Unfortunately, I had no idea the problem this observation was addressing and poor Pete had to suffer my lack of understanding for some time."

"Aha—so the point is that we are always archaeologists, à la *Collingwood, trying to reconstruct intent and purpose from what is presented to us. Even when they are giving us answers, we are faced with the problem of figuring out the questions they are answers to . . . problems at the beginning of the chapter."*

"Right, only we are going to make this process more explicit. To do this we need to find something that is tantalizing, something that is almost there, something that students thought they understood—like Meno. Then we turn a corner. We ask a question and pull the rug out from beneath their feet. We aren't starting with something completely new; instead we're taking a new look at something they already knew. By starting this way, with a problem, we acknowledge that the material is an answer to questions that people have been asking for a long time, and so we give the material the context it deserves. The key is that the lesson is not organized around an answer, or a demonstration, or an interesting phenomenon, or some activity that is meant to show how everyone should think about a topic. Instead it centers on a problem. It centers on a problem because what we really are after is for students to explore, examine, and come to make sense of things. What we really are after is that they can explain things. What we really are after is talk."

"But isn't there any value to the other sort of question that comes at the end of the chapter?"

"Yes, Sancho, but we need to be careful. We want a lot of those questions to be open. The problem is that too often they are short answer questions that don't require students to understand what's going on. You want to make sure there are questions that push the material, using what was in the chapter as a platform to move on to something else that connects but is new."

"What about here, D.Q., with this text?"

"Yes, we will work to bring things together and there will be questions, but not the sort that 'covers' the chapter . . . nothing like 'What is a Camarasaurus?' or 'Who wrote Motel of the Mysteries? *' Instead we will have a kind of afterword for each chapter.*

"The main body of this book is a sequence of eight chapters. Between chapters are interludes. These are not offered as amusing diversions. They use the chapter as a platform. Things do not speak for themselves. That is as true of classrooms as it is of dinosaur vertebrae. And classrooms and the enterprise of teaching science

are every bit as complicated with as elaborate an anatomy as the great beasts of the Mesozoic. We pause with an interlude because some quality of the things themselves would be lost if we didn't stop right there and consider it.

"I would often explain to students that teachers lie all the time. It's what we do. So that a student's job is not simply to take what is presented as 'gospel,' but instead to poke it to see if it works, and if it doesn't then raise a question. When they would ask why teachers don't simply tell the truth, I would ask them to try something. 'I want you to imagine a fourteen-sided object,' I would say. 'It has six faces that are octagons and eight that are triangles.' Can you picture that, Sancho?"

"No, I have no idea what that might be, D.Q."

"O.K., can you imagine a cube, like a die from a pair of dice?"

"Sure."

"Well, what happens if you cut across a corner of the cube?"

". . . you get a triangle."

"How many faces are there in a cube?"

". . . 6."

"And how many corners?"

". . . 8."

"And if you cut all the corners off, what's the shape of the old face of the cube?"

"I get it, an octagon. And so you would have six octagons and eight triangles, a fourteen-sided object."

"Yes. The truth, Sancho, is a many-sided object. To get students to appreciate this complexity, we always start with a cube . . . something simple. If we do our job well, we show students how the cube doesn't really work, and that we need to cut a corner here and there to make it work. All too often, however, we give students the impression that what we offer them is the whole truth. 'These are the facts.' But that's all wrong. There's always someone who knows more. For them what we have is just the beginning, a cube that needs to have its corners cut. That's what scholarship is all about . . . working out the many-sidedness of things.

"Our interludes are corner cuttings. They take a core notion and play with it a bit, connect it to the classroom, to activities, to assessments, and show where the complexities lay. In this first chapter we began with the notion that a puzzle is more important than the right answer. Perplexity provokes, it pushes. This might have struck you as reasonable, but not very realistic. After all, we are charged to teach the material and our textbooks overflow with elaborate concepts, analytical strategies, and hosts of algorithms. On top of which, it seems all of our students are below the national average. There is so much to do and they need so much help, there can't be enough time to talk about what these things really mean or engage in Socratic-like dialogues.

"For sure, time is an issue. But we also pay a price when we don't take the time. That's what this first interlude gets at . . ."

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