Memo to the Faculty

Faculty Teaching Excellence Program
Office of Academic Affairs, University of Colorado at Boulder

Number 49

Science in a Postmodern World
Kenneth A. Bruffee

It has been a commonplace among scientists and science teachers for years that college and university science education is in serious trouble. The trouble, as Sheila Tobias has trenchantly put it, is that in the past 25 years "the proportion of college freshmen planning to major in science and mathematics fell by half." Tobias's widely read study, *They're Not Dumb, They're Different*, is one of the most recent to offer suggestions for solving this problem. She proposes that the solution lies in changing the "classroom culture" that prevails in science courses. That is, she would increase the number of American young people entering science as a career by making science classrooms more "attractive and accessible." Package science more appealingly, she argues, more shoppers will buy. On this principle she cites with approval Dudley Herschbach's revisions in Harvard's Chemistry 10. By "setting a different mood" in the class, chatting amiably with students on occasion, releasing them from enslavement to "the curve," and allowing them a second chance on difficult topics, Herschbach doubled enrollment and improved test performance. There is a lot to say for this suggestion. It would undoubtedly make life a lot more pleasant for a lot of American undergraduates. But as Tobias's most recent research on revitalizing undergraduate science has shown (*Change*, May/June, 1992), putting it into effect across the spectrum of American colleges and universities may be more difficult than one might have hoped. A more serious limitation is that, as a solution to the problem of declining enrollment in college and university science courses, it does not get to the heart of the problem.

The heart of the problem is the tension between the way scientists do science and the way they tend to teach science. Scientists as scientists are bearers of a tradition of pragmatic thought that is central to Western culture, a tradition based on the interpretive ability, in collaboration with other scientists, to construct, manipulate, and calibrate models and symbol systems. As teachers, however, scientists present themselves to their students as something quite different, something a little like museum curators, as if a scientist's main job were to accumulate, maintain, and display curious and useful facts about the natural world.

Of course these two roles—scientists as curators of knowledge and scientists as bearers of a culturally central pragmatic intellectual tradition—are not inherently contradictory. Clearly there is a relationship between the knowledge that science accumulates and the intellectual tradition that contributes to its accumulation.

Nevertheless, it seems clear that the first priority of college and university science education should be to acquaint students with science as science is actually done, in order to help them become members of the pragmatic intellectual community that science teachers represent. It should not be to acquaint students, however attractively and accessibly, with the wonders of nature.

Tobias's proposal doesn't go to the heart of the problem of science education because it encourages science teachers to continue to present science as primarily a curatorial enterprise. It does so, evidently, because it relies on an individualistic, foundational understanding of science. Tobias and her colleague, John S. Rigden, have made these traditional assumptions explicit. Science, based in their view "on empirical evidence, not on authority," is a "systematic method of conversing with nature" (*The Chronicle of Higher Education*, March 27, 1991). Science teachers, by this light, must testify to the certainties and truths that scientists have adduced in that lonely conversation with nature and by means of that systematic evidentiary method.

Informed by this traditional understanding of science, Tobias's proposal has difficulty coming to terms with her
informants' most damaging remarks: that the introductory college and university science courses they took were intellectually barren. Their courses made science "into a craft, like cooking," as one of them wrote, "where if someone follows the recipe, he or she will do well," or where, as another wrote, "the basic message [is] that accountability is what doing well . . . is all about."

Fortunately for the future of science education, the traditional assumptions that underlie Tobais's proposal have been under siege by a vigorous alternative set of assumptions for at least a quarter-century. According to this alternative, science is not a methodical evidentiary process but a process of interpretive construction. In their 1986 ethnographic study of research work at the Salk Institute, Laboratory Life: The Social Construction of Scientific Facts, Bruno Latour and Steve Woolgar show how interpretive construction plays out in the everyday working lives of scientists. They demonstrate that scientists do carry on a conversation, but not with nature. The conversation scientists carry on is with each other.

Scientific knowledge, according to Latour and Woolgar, is what the members of some scientific community say, or perhaps what they are able to say—directly and indirectly, in speech and, even more importantly, in writing—to other members of that community. "The construction of scientific facts" is largely "a process of generating texts whose fate (status, value, utility, facticity) depends on their subsequent interpretation" by other scientists. A scientific lab is "a hive of writing activity" where scientists "spend the greatest part of their day coding, marking, altering, correcting, reading, and writing."

Understanding science as interdependent, interpretive, and constructive does not necessarily imply that scientists never come up with anything that could be called "truth." It does imply a particular understanding of the truth that they come up with. The interpretive, constructive conversation involved in scientific inquiry is rigorously governed, as the British historian and philosopher of science Nicholas Sardine explains in The Scenes of Inquiry, by long-established, local, everyday details of research practice by which interpretation and construction proceed—practices such as "the use of particular types of instrument . . . particular routines of observation and description" and the conventions of conversation, spoken and written, about scientific work.

The tectonic shift in our understanding of science that this constructive understanding of science represents is one that college and university science education can no longer ignore. And reading Tobais's evidence from this perspective suggests quite a different solution to the problems of science education from the one she offers. It suggests that college and university science students should be learning collaboratively how scientists confront the uncertainties and ambiguities of science by collaboratively constructing, interpreting, manipulating, and calibrating scientific models and symbol systems. In short, college and university science students should be learning how to "talk science" with each other and "write science" to each other.

Science education of this sort would benefit both teachers and students. It would help science teachers overcome the troubling difference between the way they conduct their professional lives as scientists and the way they try, as college and university science teachers, to induct new members into that professional life. It would help science students by reclaiming for introductory science courses the excitement inherent in the pragmatic, interpretive intellectual tradition that scientists represent.

In teaching science as an interpretive, constructive process, science teachers would of course continue sometimes to display what scientists believe they now know about the natural world and the changes it undergoes. But what they would emphasize is the uncertainties that scientists encounter in the interpretive process by which they build models of the natural world and calibrate those models and symbol systems against precedents and standards so as to establish them as "actual reality."

Chemistry teachers, for example, would continue to explain what electrolytes are and how they dissociate. But their primary task would be to create conditions in which students learn how and why chemists construct the model they call "electrolytes," how they construct and manipulate symbol systems that express changes in that model, and how they decide whether or not that model and those symbol systems are reliable by testing them against precedents and standards currently accepted by the community of chemists.

There is, of course, no guarantee that teaching science as a pragmatic, interpretive intellectual tradition—that is, as a collaborative, interpretive, constructive encounter with scientific uncertainty—would increase the number of American young people taking science courses. But it would almost certainly increase the proportion of those taking introductory science courses who go on to enter science as a career. That is likely to happen because teaching science in this way would almost certainly change the kind of college and university student persisting in science majors. This has caused the crisis is not just a decline in the number of students who go beyond the introductory science courses to major in science, but—as Tobais's evidence suggests—the kind of student who goes on. Many students who continue in science today are attracted to science by the same thing that students were attracted by 25 years ago: the tendency of science teaching to satisfy their "need to be griped, grasped, and compelled" by Nature (capital N), and its tendency to appeal to their hope of discovering in science a tidy world full of certainties, "a world without loose ends."

Tobais's evidence suggests, however, that fewer intellectually talented students today feel that need and harbor that hope. As a result, the vision of science presented by science teaching as compellingly certain and
coherent now disenchants many students. That is why they are more likely to be tempted away from science, as Tobias's informants had been, by the humanities and social sciences, where they find the quality they fail to find in their science courses: the intellectual rewards and excitement of trying to cope with uncertainty, ambiguity, and a world full of loose ends.

Most science teachers are familiar with the other kinds of students these intellectually talented and adventurous students leave behind when they go. Advanced science courses tend to be saturated with students of the sort that one articulate informant found in his physics class. His classmates, he said, for the most part appeared to be "cleancut and serious . . . intellectual warriors" who seemed "bored," "scared," and "dull," were not "particularly interested in making friends or seeing each other outside of class," seemed to "lose patience" with "silly 'why' questions," and were satisfied with (or perhaps dependent upon) educational experiences that ask "only for a simple exhibition of skills acquired."

Looking at the decline in undergraduates opting to study science in terms of kind rather than just number changes our understanding of the problem considerably. As studies show, talented students avoid science not merely because they are unprepared for its rigors. In the past 25 years the needs and hopes of intellectually gifted college and university students have changed, but the needs and hopes that science teachers feel called upon to satisfy have not.

If that is so, then the solution to the problem of declining enrollment is not to adjust pedagogy so as to make introductory science courses more user-friendly. The solution is to design introductory college and university science courses that will hold the interest of intellectually more adventurous students and suggest earlier to less adventurous ones that some career goal other than science might be more realistic for them.

What kind of introductory college and university science course is likely to do that? Does "intellectually more adventurous" necessarily mean "tougher" and "more rigorous"? Not necessarily. But it almost certainly means more collaborative, more conceptually intriguing, and a lot less tidy.

A complaint that appears in the notes of several of Tobias's informants hints at what such a course might be like. Several record a spontaneous tendency to challenge traditional scientific certitudes. One of them comes to the conclusion that "the law of conservation of energy . . . [is so 'artificial' as to be 'bogus'] because of all the "qualifiers" that "you have to include . . . to make the balance come out right." Another records his suspicion that some of the conventions involved in the calculations he is asked to do in studying Newtonian mechanics, quantities such as "normal force" or "the force perpendicular to the contact surface," are "not really understood" but are "made up . . . just to make the calculations work out." Still another, taking chemistry, arrives at a similar conclusion about the lattice energy curve representing attractive forces among ions.

What troubles these students is not the difficulty of concepts they had to bend their minds around but the issue of belief in scientific knowledge. They are resisting the scientific orthodoxy presented to them in introductory science courses, the belief that "facts are facts and . . . [that] there is, in the final analysis, only one right answer." Each student is asking "to what extent are those scientific facts believable?" Does scientific knowledge correspond exactly to the physical processes to which it seems to refer? If so, how? If not, then how does scientific knowledge "work," and what function does it perform? How much confidence should we really be placing in the scientific knowledge that we generally accept?

An introductory science course taught as a pragmatic intellectual tradition would take seriously the issue of belief in scientific knowledge that these students raise. For example, instead of suggesting—as Tobias does—that, in questioning conventionally stipulated definitions, the student of Newtonian mechanics was only "playing with language," such a course would begin by recognizing that the student really was on to something. He had caught physicists themselves playing with language, and in doing so he had discovered that the issue of belief in science is a troubling one even at high levels of scientific sophistication.

When pressed, of course, the scientists who taught these students told them that many of the conventions of science are "really just . . . a way of freezing a system at a moment of time, a descriptive tool," and that "nothing works across the board." No scientist would deny that scientific knowledge involves a great deal of uncertainty and language-play at every level. The point, however, is that these students' notes show that the uncertainties of science—marginal issues in the courses they took—were central to their own concerns.

The uncertainties of science and its interpretive and constructive nature should not be found on the margins of introductory college and university science courses. They should be found at the center of them. There are at least four reasons for placing them there. First, the concerns about the uncertainties of science that Tobias's informants expressed are widely shared. Second, we are better prepared today than in the past to discuss the uncertainties of science cogently. Third, the issue of belief in scientific knowledge is relevant to postmodern notions of liberal education. And fourth, the belief issue is relevant also to a significant, coherent change in pedagogical practice that is already under way in colleges and universities throughout the country.

I have just been discussing the first of these four reasons. The issue of belief in scientific knowledge is already on many students' minds, waiting to be addressed when they enter a college or university science classroom. As Karen Knorr-Cetina puts it in The Manufacture of
Knowledge, science is "no longer taken for granted as a social resource," even by the general public. The "crisis of legitimacy" in science, widely discussed in both academic journals and the popular press for more than a decade, concerns everyone: lay people, beginners, and scientific experts alike.

The crisis of legitimacy of the sciences is confirmed and fostered, furthermore, by a change in the relationship between scientific communities and other academic and professional knowledge communities. During the past 20 years or so, science has become less of a universal model of thought by becoming less of a source of explanatory metaphors in other disciplines.

For some three centuries (roughly speaking, from Newton to Einstein) the empirical, "positivist" language, assumptions, and methods of the sciences were revered as the most powerful intellectual processes ever devised. "Unscientific disciplines"—the humanities and, especially, the social sciences—aspired to increase their rigor and influence by making themselves over in the image of what they supposed to be "scientific." In the humanities and social sciences during the past quarter-century or so, however, what Clifford Geertz in Local Knowledge calls a "refiguration of thought" has occurred. The "nonscientific" disciplines have turned increasingly away from science for intellectual models and metaphors and turned increasingly instead to each other. Social scientists these days, he points out, "are chattering about actors, scenes, plots, performances, and personae, while humanists are mumbling about motives, authority, persuasion, exchange, and hierarchy."

As a result of this tendency of "many social scientists no longer [to] imitate the sciences" and draw analogies "from the crafts and technology," the sciences have lost some of their intellectual cache. Tobias is certainly right that science is "too little 'spoken' in the nation's households" today. But equally to the point, science is "spoken" less today in the conference halls and publications of scholars in every field.

To ignore the issue of belief in scientific knowledge, therefore, is only to suppress it. And to suppress it is to divide potential science students into the two categories they tend to be divided into today: students who willingly submit to being mystified by unreasoned belief in scientific certainty, and students who opt out into other fields that they find "more interesting," fields that tend to demystify knowledge by addressing rather than suppressing the issue of belief in our understanding of knowledge.

The second reason for teaching science as a pragmatic, interpretive intellectual tradition is that today the uncertainties of science, along with the uncertainties of every other field of knowledge, are easier to deal with systematically than ever before. In fact, we now have a well honed set of tools for dealing with them. To use these tools to create conditions in which students could learn how scientists accommodate inexactitudes, uncertainties, conventions, arbitrariness, and language-play would be to teach science as a pragmatic intellectual tradition.

It is, of course, primarily for scientists to say how this should be done. But it is clear that at the center of the issue of belief in scientific knowledge will be found a set of questions about the relationship between language and what it "refers" to. Does language "name things" and therefore correspond in some inherent way to ideas, objects, and actions? Or is the relationship between language and things purely conventional? And if it is purely conventional, then what can it possibly mean to "know" something?

In science, this question of "reference"—hence the issue of belief in scientific knowledge—becomes the question "What does it mean to 'explain' a physical phenomenon?" In many cases, this question comes down to the appreciation of mathematics, which, as most scientists readily acknowledge, is from the very start adventitious and artificial. As the teacher of one of Tobias's informants puts it, what matters in the sciences is finding a mathematical concept that "works."

Even relatively unsophisticated introductory science students sense the artificiality of applied mathematics. Several informants raise the issue explicitly. One of them says, for example, that "what her professor and her recitation instructor thought they were doing to explain the difficult material (describing physical phenomena in terms of the laws of physics [expressed in mathematical formulas]) didn't feel like an explanation" to her. Another states the underlying principle outright:

Formulas [she says] are used to describe strange, unknowable quantities, or [express] relations that are necessary merely for consistency.

What these students intuit is that mathematics is a construct—a systematic contrivance of signs, the criteria for the integrity and authority of which are internal coherence, elegance, and depth. Mathematics is a language, a kind of writing, a form of discourse. The application of such a highly artificial system to the physical world results in a kind of fiction—stories that mathematicians tell. In science, mathematics is a wonderfully consistent, and therefore wonderfully convenient and useful, analogy or metaphor.

Certainly a mathematical statement may turn out to correspond consistently to a physical process it is applied to, but there is nothing about mathematical language that makes that correspondence necessary. For scientific innovators—that is, scientists who are the first to apply some mathematical system to some seemingly regular physical process—a mathematical statement is a means of justification. As the first to discover that some mathematical system or other "works," scientific innovators use the right mathematical statement to justify, before a particular community of scientists, a set of beliefs they have arrived at, in order to gain that community's agreement and acceptance.
Once the community agrees that the application "works," the mathematical statement becomes entrenched in the language of the community: no longer is it regarded as an analogy or metaphor. Acceptance by the community, by virtue of the statement’s predictive power or methodological efficiency, transforms it, for all the intents and purposes of that community (although perhaps only for the time being), into an analog of the physical process in question and an explanation of it.

Tools for analyzing the referentiality of language have been developed and sharpened in discussion among literary critics for some 20 years. One way students could approach the interpretive, constructive way in which scientists achieve and maintain a practical relationship between mathematics and the physical world would be by exploring the scientific implications of this discussion.

The discussion has two parts. The first part hinges on the linguist Ferdinand de Saussure’s case that language does not refer to things in the world or to the "ideas" that we maintain for them in our minds. Instead, Saussure said, language functions by reference to other language—the conversation going on within the relevant discourse community. Use of a term depends upon conventions agreed upon among those who are fluent in the language being spoken. It is a process that even amateur scientists and lay mathematicians will recognize going on currently and throughout the history of math and science.

The second part of the referentiality-of-language discussion is about what this assumption of Saussurean linguistics must mean to our sense of "knowing" something. This issue emerges in the philosophy of Ludwig Wittgenstein, for whom what we call "knowledge" is one or another "language game." True statements for Wittgenstein are moves in the particular game being played; changes in knowledge are changes in the rules of that game; and "a necessary truth," in Richard Rorty’s paraphrase, is "a statement such that nobody has given us any interesting alternatives which would lead us to question it."

In pursuing this discussion, literary critics have asked the question "If fictions such as the great novels, plays, and other cultural artifacts that we treasure do not refer to ‘life’ or even to our ‘idea’ of life, then just how do they ‘work,’ and what functions do they perform for us?" Applied to science and mathematics, the questions would presumably be similar: "If fictions such as models of electrolytes, \( E = mc^2 \), and other scientific artifacts we treasure do not refer to ‘nature,’ or even to our ‘idea’ of nature, then just how do they ‘work,’ and what functions do they perform for us?"

New analytical tools such as these have not yet, to my knowledge, been applied broadly and systematically in teaching the sciences. But they are now there for the asking.

The third reason for teaching science as a pragmatic, interpretive intellectual tradition is that it would return the sciences to their legitimate place in the curriculum of "the liberal arts and sciences."

There are surely as many definitions of a liberal education as there are curriculum committees trying to define it, but most of these definitions have in common three goals: 1) to introduce students to the depth and complexity of human thought by familiarizing them with some of the principal beliefs that we human beings hold about ourselves, about each other, and about the physical world; 2) to introduce students to some of the ways human beings arrived at those beliefs; and 3) to introduce them to some of the ways in which those who hold those beliefs justify them to themselves and to others.

The beliefs of science are—or should be—among the beliefs that students become familiar with through a liberal education. Some 65 years ago, Alfred North Whitehead officiated with high hopes at the marriage between the liberal arts and sciences with the publication of his Lowell Lectures, *Science in the Modern World*. For some 30 years, the encouragement and counsel of that widely read volume kept the marriage intact. Today, however, science courses and the liberal arts curriculum have been divorced for decades, largely by common consent. As a result, students frequently complain with good reason, as one of Tobias’s informants puts it, that undergraduate science courses "train" students, they do not "educate" them.

In the 1990s, *Science in the Modern World* is a historical document. To many of us, its foundational scientific and philosophical assumptions seem antediluvian. Yet Whitehead’s motive remains valid. To Whitehead, those who do not understand the cultural importance of the sciences are, in his word, provincial.

To teach the sciences as an interpretive enterprise would help reduce this provinciality. Approaching science as a pragmatic interpretive tradition would contribute to liberal education by showing that, along with literature, philosophy, religion, music, history, and the arts, scientific knowledge comprises a set of beliefs. It would show how these beliefs are justified, how they became established, how they have been challenged in the past, and how they are being challenged today—both from within disciplinary communities and from without.

In pursuit of this goal, one invaluable resource is likely to be Arnold B. Arons’s *Guide to Introductory Physics Teaching*. Chapter 12 of that book, "Achieving Wider Scientific Literacy," should be required reading not only for every science teacher, but for every college- or university-wide curriculum committee member, scientists and nonscientists alike.

The fourth reason for teaching science as a pragmatic, interpretive intellectual tradition is that in focusing on the uncertainties of science, it would make possible the organized, open-ended conversation that is necessary for genuine collaboration among students and hence for the cultivation of the craft of interdependence. Tobias offers an
example of one kind of collaboration, a student's experience in a chemistry "tutor room":

I would go in, sit down at one of the three tables with some other people I didn't know [the student says], and pretty soon we would all be discussing the material and working the problems together. Whenever we were stumped, we could bring one of the tutors over to the table to help us out. It was a very good system. Here we had a solid block of time . . . to interact with other students, work problems, discuss, and actively learn the material we were covering in the lecture.

The micro-conversation that occurs among students working together in small groups such as this student describes helps them improve their grades by giving them an opportunity, as another student puts it, to "practice talking physics" and, of course, to practice writing physics as well. This is the principle motivating Uri Treisman's program organizing university science and math students into mutually reacclimating, self-help study communities at Berkeley and Texas, and it is also the principle underlying the research in teaching medical students that M. L. J. Abercrombie reports in The Anatomy of Judgment.

Yet simply adding "small groups" to science classes will not achieve fluency in the language of the relevant scientific community that an interpretive, constructive approach to science can achieve. Only integrating collaboration systematically into courses by changing the nature of the tasks students undertake together will achieve that.

The problems that the chemistry student and her fellow students were solving together in the chemistry "tutor room" were closed-ended, result-focused, foundational jigsaw puzzle tasks, the kind of tasks usually found in problem sets. In the context of an interpretive course in which the goal is to confront the uncertainties of science, problems of an open-ended, interpretive, non-foundational tool-making kind would make peer-group work still more rewarding. It would make it genuinely collaborative instead of being merely a matter of helpful cooperation and teamwork.

Under these conditions, the micro-conversation going on in peer-group work tends to model the conversations in which scientists actually construct knowledge: whether they are direct conversations (person to person); conversations displaced into writing, publication, or computer networks; or conversations internalized as thought.

One way to apply this principle would be to make laboratory work more genuinely interpretive, constructive, and collaborative. This is a conceptually and logistically complex issue. But it is worth tackling, because today most undergraduate lab work has been assimilated to the authority structure of the lecture hall. Most lab work today also assumes that students have already gained fluency in the relevant scientific language; that they can already talk or write physics, chemistry, or whatever.

Making lab work genuinely collaborative would reverse that vector of authority by assuming that the lab is where fluency in "science" is to be acquired. Then laboratory work really would approximate the way Bruno Latour and Steve Woolgar show that scientists do science. It would approximate the buzz of "conjoined intelligence . . . made by confluent, simultaneously raised human voices, explaining things to each other" that Lewis Thomas hears on the beach at the Woods Hole Marine Biological Laboratory in Lives of a Cell: the conversation among scientists making sense out of what they observe by negotiating their differences.