

TEACHING SCIENCE BY SEMINAR

George Greenstein

It's no secret that fewer and fewer students are taking up science nowadays. I'm sure people at your institution have been tracking the trend. They certainly do at mine, with much worrying and shaking of heads.

Have we been doing something wrong? There are plenty of social and economic factors involved in this widespread decline, factors over which we have no influence. But I want to concentrate on one element we do control. It has to do with the way we teach our subject, at both the undergraduate and graduate levels. I believe many of the best students opt out of science for perfectly valid reasons. Students in the sciences labor under certain special difficulties not faced by those in other fields. These difficulties are intrinsic to the sciences, and they make it particularly difficult to be a science student. Back when social forces tended to push students toward the sciences, these difficulties had little influence on science enrollment. But now that the social pendulum has swung the other way, they work to steer students away.

As we lecture to them, our students' sole task is to make sure they understand what we are saying. This is an essentially passive task. In contrast, when these same students take a course in the humanities, they are likely to be far more active: They work out their own—their own—ideas and pay attention to these ideas' consequences; they express their thoughts in coherent form; and they criticize the presentations of their fellow students. That humanities course is likely to be a seminar. Why are seminars so common in the humanities and the social sciences? Be-

cause of the many advantages of this mode of instruction. The seminar course, if it works well, encourages students to become active participants in their education. The lecture course, on the other hand, tends to force the student into the role of passive observer.

This enforced passivity is endemic to instruction in the sciences. It follows from the highly technical nature of the field, for only lectures are capable of transmitting efficiently great amounts of information. When we teach undergraduates the Maxwell-Boltzmann distribution or hydrogen-atom wave functions, we are exposing them to something technically complex and far removed from their personal experience. It is essential that they shut up, buckle down and seek to understand what we are saying.

By contrast, humanities and the social sciences deal with matters to which everyone has a direct, personal connection. The philosophy major reading up on the mind-body problem already knows what it is to have a body and a mind. The literature student analyzing *King Lear* has already experienced the emotions that beset Lear. It is significant that our colleagues in the humanities commonly give courses on the very subjects of their professional concern. They teach what they are working on, and they often find their students' comments, even those of undergraduates, helpful in clarifying their thinking.

But science students are incapable of telling their instructors anything worth listening to—not because they are stupid, not because they lack insight or creativity, but because they lack the technical knowledge. It would be the height of foolishness to ask for a student's opinion of the divergence theorem; the only point is to get the matter straight. So, students of the sciences are forced into an es-

entially passive, helpless stance, where they remain until they are well advanced in graduate training. And this is deeply frustrating to young people—particularly to the best of them, the ones we would most like to attract. How many times have we heard from our students the old familiar complaint that science is cold, inhuman and uncreative? We like to think that these students are wrong, for we know there is endless creativity to science and plenty of warm human drama to the process of discovery. But, when we think in these terms, we are thinking of *our* experiences, not those of our students as they sit silently in the classroom, struggling to understand what we are telling them.

Lecture courses, by their very nature, tend to exacerbate the problem. Seminars would help to alleviate it. There is another element to the seminar method that makes it attractive. All of us are aware that there is a messy, groping quality to research that is absent from the perfect lectures we give in our courses. Such clarity and logical inevitability are what we strive for in our work, and, if we are lucky, what we attain in the end. But the end is not representative of the halting, error-prone means by which we reach it.

The scientist faced with a new phenomenon is seldom capable of formulating a well-defined approach to it. More often, one circles around the phenomenon, trying approximations, separating out this or that element of the situation and treating it in isolation. Only after years of this sort of work does an understanding emerge of the essential elements of the phenomenon—one so clear that it can be presented in a textbook. The ability to carry out this sort of work is an art, not a science, and we need to find some way to teach it.

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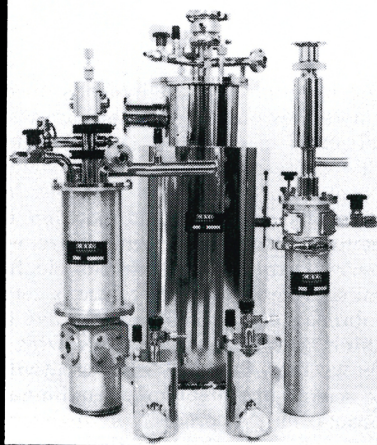
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I would argue that a good strategy is to back away from our traditional emphasis on problem sets. Rather than asking students to solve problems, we need to ask them to formulate problems—the right problems, capable of solution and representative of the situation under investigation. The lecture course is no place to do this. But the seminar, with its emphasis on requiring the students to do the talking, is ideally suited to this task.

It's true that seminars are used from time to time in the sciences, particularly at the freshman level. Students may read a *Scientific American* article and then get together to discuss it. But I want to advocate a different use for the seminar, one designed to address the issues I have raised here.

In 1989, with the help of a Pew grant to the New England Consortium for Undergraduate Science Education, Suzan Edwards of Smith College, Stephen Strom of the University of Massachusetts and I designed a junior-senior undergraduate seminar course in astrophysics. So far as we know, it is unique. There are no lectures, no problem sets and no reading material of any kind. What we do have is a set of questions—loosely expressed and pertaining, as it happens, to the currently active field of star formation. (Because the rate at which students proceed through a seminar cannot be predicted or controlled, it is unsuited to normal "bread and butter" courses. But it is perfectly suited to special topics.) Among the questions we use are, How can we find out if star formation is going on right now within the galaxy? When stars form, do planets commonly form along with them? These are the kind of questions that we, as practicing scientists, seek to answer—and they are most definitely not the kind of questions we normally assign in problem sets.

On the first day of class, after the usual preliminaries, we turn to one of the students and ask one such question. The student's response is instructive: He or she usually reacts with something approaching pure terror. After much hemming and hawing, a class discussion gets under way. The students' initial desire is to head for the library to look up the answer. Only when we prevent this and force them to analyze the problem for themselves does any actual thinking begin. Of this thought process, several points are worth noting. On the one hand, students tend to focus exclusively on one tiny piece of a question, analyzing it in full and entirely

unnecessary detail. They vie with one another in pointing out endless new and complicating minutiae. On the other hand, what we would regard as the very essence of the situation often gets overlooked. At this preliminary stage of analysis, a back-of-the-envelope calculation would be most appropriate, but the students often actively resist such an approach. They are fresh from a lecture on Bessel functions or CCDs, and a back of the envelope calculation seems too pedestrian for their tastes.

Many of the course's questions can be adequately addressed by such a quick, in-class calculation. Others require more extensive mini-research projects—and it is the students who must design these projects. At this stage, they sign up to work individually with the instructor, completing the work within perhaps a month and reporting to the class on the results. Some of these projects are theoretical in nature, while others are observational, and, by some feat of clairvoyance, real data taken in advance are available for their use. The course consists of a series of these projects, interwoven to present a broad overview of the field.

Obviously, there are plenty of difficulties with this mode of instruction. Class discussion can be maddeningly slow and often wanders off in fruitless directions: Accustomed to speaking, the instructor now must learn how not to speak. Individual students—usually male—tend to dominate the conversation: One must know when and how to intervene, and delicate interpersonal skills are vital to the success of the enterprise. Essential subjects may simply never come up: One needs to decide whether and how to introduce them. And finally, while there are no lectures for the instructor to prepare, one spends much time working individually with students, so that it is difficult to give the course to more than 10 to 15 students at a shot.

But for all these disadvantages, we who have taught this course cannot speak too highly of it. It is no exaggeration to say that when it is going well, it achieves ends no standard course can achieve. I would never argue that we abandon the lecture as the dominant mode of instruction in the sciences; it is too perfectly suited to the needs of the field. At the same time, however, it makes sense to lighten our traditional lecture curriculum with the more informal, free-form instruction that the seminar provides. ■