

**They're
Not
Dumb,
They're
Different**
*Stalking the
Second Tier*

by SHEILA TOBIAS

An occasional paper on neglected problems
in science education

*Published by Research Corporation
a foundation for the advancement of science*

(Tucson, Arizona, 1990)

have done science in college. But, except for some pressure from ROTC during his senior year in high school, Eric was not recruited to science either in college or before. Nor, despite his high school background, was he emboldened to try science as an elective. Eric had other options and developed "other loves" in college. Since he never appeared in a science course, no one in science ever got to know him (any more than he got to know them). As a result, there was no one, neither awesome professor nor friendly science teaching assistant nor science-trained college counselor available to him when, in the middle of his undergraduate career as an English major, he felt the need for more rigorous study outside of English. Observing that it was the treatment of *ideas* in literature and, especially in literary criticism, that attracted him to English more than the sheer aesthetic pleasures of poetry and fiction, Eric at one point considered a shift into philosophy. But he found philosophy, as currently practiced, narrower still, and so he stayed in English. Until recruited for this project, Eric never reconsidered science as a course of study or as a career. His journal and his postcourse reflections on the experience of taking college physics last summer give us insight into why.

Professional scientists may be tempted to dismiss comments and criticisms from second tier stand-ins as but further "proof" that they are not "one of us." But that would be missing the point. If the sciences are to attract any new group of students to science, either to meet the projected shortfall or to solve the science illiteracy problem, the effort must begin by getting to know some of "them," and well.

Introductory Physics: The Eric "Experiment"

"The notion of a 'calling' is deeply ingrained in the mythology and history of science. If we assume that all students are 'called' in the same way and by the same age, we fix what is inherently variable—the size and composition of the talent pool."

—Daryl Chubin¹

Eric found it "strange" to be in class again, especially in a lecture class where "everyone looks tired" and no one seemed particularly excited by the prospect of the five-week introductory physics course that lay ahead. His fellow classmates, as he perceived them, were either "bored" or "scared," he noted on the first page of the daily journal he was keeping of his reactions as a literature student to introductory physics. In even the most obscure literature class, he wrote, "there are always people who are intensely interested, at least at the outset. Is it simply the nature of the subject that makes elementary science classes appear unexciting, or is it the teaching style?"² Part of his assignment, as a participant-observer for a project supported by Research Corporation, was to find out.

Because it was a summer session, Eric would not experience the anonymity of the larger classes that characterize introductory physics. He shared his course with only 30 others, 20 men and ten women (not the gender balance he was used to, as he recorded in his journal). But the habit of teaching large classes and the demands of the fast-paced summer-school schedule prevented his instructor from modifying the lecture format. One look at the assignment sheets and at the weight of the text³ gave Eric some sense of the amount of material to be covered, and some anxiety. To add to his travail, he discovered his calculator wouldn't handle exponents when he began to work the problems that first evening (he borrowed an HP 15-C the next day). More serious was his worry that, although he had taken college calculus (a condition of his assignment as participant observer in this course), his brain

¹ Daryl Chubin of the Office of Technology Assessment, U.S. Congress, made these remarks during a talk at the AAAS National Meeting, New Orleans, Feb. 17, 1990. Quoted with his permission.

² Eric, of course, was not around after class when the few students who were intensely interested in the subject went up to speak to the instructor.

³ Halliday and Resnick, *Fundamentals of Physics*, Third Edition, New York: John Wiley, 1988.

wouldn't handle the computations. And it was clear there would be no respite either from the pace or the expectations. "The instructor gave the class the impression," Eric noted on the first day, "that since *he* had had to make it through the 'elementary grind,' so must we."⁴ Literary studies offer a different kind of challenge, Eric noted right away. "In literature," he wrote, "the cutting edge is accessible, even if it is unlikely to be mastered by a beginner. In physics, a correct solution may be harder to figure out, but once done it will be indistinguishable from the professor's own." This insight soon became palpable for Eric when he discovered the "one nice thing" about physics: "as I try and endure, the understanding comes. And this does not necessarily happen in the humanities."

On the second day Eric began to notice more profound differences between the "values," as he put it, of a person in the humanities and those of a scientist.

In a discussion of one of the homework problems, we were to judge the best clock for timekeeping, given a record of five clocks' readings at exactly noon. The professor chose the clock that gained exactly 51 seconds every day. I picked the clock that was within seven seconds of noon, day after day. A scientist wants predictability. I would rather have convenience.⁵

But the first "real day" of lecture disappointed him.

The class consisted basically of problem solving and not of any interesting or inspiring exchange of ideas. The professor spent the first 15 minutes defining terms and apparently that was all the new information we were going to get on kinematics. Then he spent 50 minutes doing problems from chapter 1. He was not particularly good at explaining why he did what he did to solve the problems, nor did he have any real patience for people who wanted explanations.

Eric was learning that, for the most part, "why" questions are neither asked nor answered. The preference is for "how" questions. Perhaps because of this, his initial assessment of the teaching mode (compared to what he was used to) was negative.

I do not feel that what this professor is doing can be considered teaching in any complex or complete sense. My understanding is that we are to learn primarily by reading the

⁴ The instructor, reading these comments, did not recall ever using the term "elementary grind," but agreed that he brought to his teaching certain prejudices about who takes summer school physics and why: he assumed his students were "preprofessionals who have already decided on a career in science and are in class to learn problem solving." After reading these comments, he conceded he needed to be "more guarded about what I say..." and that "extreme care must be taken to set a good mood for the course, and to offset the prejudices students bring with them."

⁵ Page 11 in the text, question 30P.

text, secondarily by doing problems on our own and comparing our solutions to those on sale in the physics office, and thirdly by mimicking the professor's problem-solving examples. Simply by intuition, I know physics, and more generally science, to involve creativity and finesse; but this man makes it into a craft, like cooking, where if someone follows the recipe, he or she will do well.

There was, indeed, a discrepancy between Eric's expectations and those of his professor (note 4).

By the end of the first week, classes seemed a little better or maybe, as Eric wondered, he was just getting "used to the way [the course] is being 'taught.'" Still, he felt patronized by the teaching style.

I still get the feeling that unlike a humanities course, here the professor is the keeper of the information, the one who knows all the answers. This does little to propagate discussion or dissent. The professor does examples the "right way" and we are to mimic this as accurately as possible. Our opinions are not valued, especially since there is only one right answer, and at this level, usually only one [right] way to get it.

It was not the physics that bothered him. In later segments of his journal he would praise the text, a book borrowed from the physics undergraduate office that he begged to be able to keep when the course was over. He found his old love of math coming back. In the quiet of the university library where he spent afternoons trying to work the problems, he was "really quite content," he wrote. It was the class that bothered him most at the beginning, but he was honest enough to realize that as he "got more into the physics," he liked it better.

As I am able to ask more knowledgeable questions, class becomes more interesting. I am finding that while the professor is happy to do example problems for the entire period, he will discuss the real world ramifications of a theory if asked.

His classmates didn't appreciate his interruptions, however. They seemed to "lose patience" with his "silly 'why' questions." These got in the way of the mechanics of finding the right solution to their assigned problems. And this was what, as Eric perceived it, physics was all about—for them.

He was finding more differences between doing physics and doing literary analysis. The professor's suggestion that setting up the problem and understanding concepts is more important than doing the arithmetic reduced Eric's homework time from six hours per night to three. He was happy to be relieved of some of the computation, but bothered, too. "Imagine being asked to show only that you *could* write a paper on the use of gender in *Tom Sawyer* without having actually to do so," he wrote in his journal that night.

Two weeks into the course, Eric was becoming skeptical about some of the models. His attention to language and his continuing need for answers to "why" questions was decidedly getting in his way. His July 9 entry reads:

OK, I might as well admit it now. I don't really believe Newtonian mechanics. It works, yet somehow I think there are various forces which are made up—not really understood—just to make the calculations work out. Is there really a normal force?⁶ The force which pushes a book down on a table is gravity. Yet the "normal" force which comprises the table pushing back on the book, seems a little strange. Why should a table push on a book? Maybe it should be called the "abnormal" force? And action-reaction seems to me to be a misnomer... "Action-reaction" presupposes a cause and effect relationship which implies duration, but in physics the "action-reaction" happens simultaneously.⁷

By then he was starting to look around a bit more at the students in the class. Everyone looked clean cut and serious, he noted. Yet, there were a few people who caught his eye.

There is one man with a crew cut who always sits in the front row and always wears a hat that says, "Life is too short to dance with ugly women." Another extremely muscular "frat boy type" catches my attention only because he always mutters the right answer several seconds before anyone else. I have decided he is either a genius or he has taken the course a few times before. There is a Hispanic woman who sits next to me who is already having trouble with the material. She tells me she spends seven hours a night on homework and needs to get an "A" to receive an ROTC scholarship for next year. A pretty blonde premed sits behind me. She acts like she wants to be friends, but her conversations always eventually turn to, "...By the way, what did you get on problem 57?"

Yet, even though the class was small, there was "no sense of community within the class," Eric noted, a fact he would later comment on at length. He attributed this to the lecture format and to the subject, devoid, as he put it, of "personal expression."

⁶ Eric knew full well by then that the normal force in physics is the force perpendicular to the contact surface. He was playing with language.

⁷ According to Arnold Arons, professor emeritus of physics, University of Washington, Eric's question concerning time intervals elapsing in connection with force adjustments having to do with Newton's third law, "is one of the deepest questions arising in classical physics. The question must be planted deliberately, and students must be led to think about and discuss it. There are very very few Erics who raise it spontaneously." (Personal communication to the author.)

Nobody seems particularly interested in making friends or seeing each other outside of class. This may be one reason people dislike math and science classes, their lack of community.

The first exam gave Eric some important insights both into how physics is taught and why the sense of community was so lacking. He personally found the exam "easy," easier than the homework which, as he expressed it, "involved the use of multiple concepts and numerical manipulations." In contrast, he wrote in his journal, "the exam problems asked only for a simple exhibition of skills acquired." He was "frustrated" to have spent so much time on problems which he would not encounter on tests. Later he concluded that the homework problems were really too hard, "discouraging rather than encouraging. Sometimes you are asked to display a knowledge of so many concepts at once, it is hard to get a hold of things."

But the real impact of the exam was felt when the exams were returned to the class.

When we got our exams back this week, everyone was concerned about how other people scored. I understand that natural curiosity and in my literature classes there was always some comparing done between friends. However, I've never experienced the intense questioning that has happened this week. Almost everyone I talk to at some point or another asks me about my grade. When I respond I scored an "A,"⁸ I get hostile and sometimes panicked looks. It is not until I explain that I'm only auditing and that my score certainly will not be figured into the curve, that these timid interrogators relax.

There was, in fact, no "grading on a curve" in Eric's course. The course handout had specifically stated this. Primed by other courses in science, students assumed they would be graded on a curve. The fact that the professor posted a histogram after each exam with the break points for the letter grades may have confused them. The professor said later, "maybe the students think a histogram implies a curve." His classmates' behavior, however, suggested to Eric that they fully believed grading was on a curve.

It wasn't until this afternoon that a classmate explained to me that students in a science class try to identify people who score well and then constantly compare their scores (or time studying or answers on homework) to their own. I have never been in a class before where my grade had any effect, real or perceived, on anyone else.

⁸ Eric did very well in the class. He never got the grade on his final exam but he averaged 92 during most of the course. See below for more of his comments about the examinations and the grading system used in his course.

Even more basic, for Eric, was the class' fixation on grades.

Why is it so difficult to get a good grade? For one thing, there are less of them. Due to [perceived] curving in physics, the grades are based on the class average which kills any spirit of enjoyment. The message (though surely not intended) seems to be that no matter how hard you work—so long as everyone else works as hard or has more talent or experience—you *cannot* improve your grade.

Eric found the "sense of competition" in no way beneficial. "It automatically precludes any desire to work with or to help other people," he wrote. "Suddenly your classmates are your enemies." No wonder the class was not "fun," and there was so much hostility between students.

My class is full of intellectual warriors who will some day hold jobs in technologically-based companies where they will be assigned to teams or groups in order to collectively work on projects. [But] these people will have had no training in working collectively. In fact, their experience will have taught them to fear cooperation, and that another person's intellectual achievement will be detrimental to their own.⁹

Still, he was impressed with his fellow students. Although the class continued to look "tired and bored" to him, he noticed that they "stick with it." He found there to be a "much more practical attitude about this class" than he had experienced in humanities. People think "yes, this is dull, but I have to complete this course to get my degree or to get a good job."

In my literature classes it was much harder to rationalize this way. People took courses mainly because of interest in the topic or because they thought the professor would be good. It is not that a science course cannot be or isn't interesting, only that it's not required or expected by the students that it be so.

While some of the concepts were difficult for him and he continued to be bothered by the "constant qualifiers" such as "assume a frictionless surface," it was the pace of the course that he found "excessive, almost insane."¹⁰

I usually give myself three hours for homework and never finish...I feel, though, that I have sufficient control of the subject matter [studying this way] to do well on the exams.

⁹ The issue of teamwork is a centerpiece of modern science. See Daryl Chubin et al, *Interdisciplinary Analysis and Research*, Lomond, 1986.

¹⁰ The professor himself admitted that the pace was "preposterous." Mindful that a summer school course is not typical, we continued the experiment with semester-long courses in the following fall. See *infra*.

Most of the other students I have talked to take six or seven hours a day to do the work...Aside from the pure misery of devoting that much of your life to physics, I wonder how much they, or rather we, will retain. I think that a slower pace and more in-depth discussions of the contents would, in the end, prove [more] beneficial.

He found the time demanded to be considerably more than he ever spent in literature—three hours per course hour in physics versus two hours per course hour in literature. Moreover, as he wrote during the third week, "physics homework demands a more intense, highly active type of thought."

Reading, however critically done, is a more reflective activity. There isn't the demand for almost instantaneous application of the information. The result of this difference is that two hours of physics is much more demanding and tiring than two hours even of [academic] reading.

The drawbacks of this amount of time spent may not be immediately apparent, he wrote. However,

with my extra time [as an undergraduate majoring in literature], I was able to pursue many different and independent types of educational experiences. Some of this included designing and running my own course, and [when an upperclassman] writing a grant-supported research paper. The science student is more often than not limited to the struggle of just completing required work.

When Eric asked himself, midway in the course, "what makes science hard?" he came to a preliminary conclusion that students will perceive a course to be "hard" when it is: 1) difficult to get a good grade; 2) time consuming; or 3) boring, dull, or simply not fun. Physics he found to be all of the above. But why introductory physics should be thought of as "dull" intrigued him. He kept coming back to the lack of community and the lecture format.

The lack of community, together with the lack of interchange between the professor and the students combines to produce a totally passive classroom experience...The best classes I had were classes in which I was constantly engaged, constantly questioning and pushing the limits of the subject and myself. The way this course is organized accounts for the lack of student involvement...The students are given pre-masticated information simply to mimic and apply to problems. Let them, rather, be exposed to conceptual problems, try to find solutions to them on their own, and then help them to understand the mistakes they make along the way.

But the concepts weren't easy and sometimes they didn't get cleared up at all.

For some reason I am unable or secretly unwilling to complete these statics problems. Nothing seems to make sense and for the first time since my initial anxiety attack, I feel a cloud of bewilderment around my head...Tomorrow will give me a good opportunity, however, to see what venues are open to a student who is "lost." I will try buying a solution sheet and see if the problems make sense. If they still don't, I will go to office hours, an activity I've always hated. Someone who is clever will always get by; but what of someone who isn't? Is the measure of a course how much a bright student learns or how much someone who is "lost" can be made to comprehend?

Getting help was not easy for Eric or, he thought, for the others, despite the small size of the summer school class.

If you find you do not understand something from the last chapter, you must wait until after class to see either the professor or the teaching assistant. The professor's office hour is busy and there is not much time for in-depth help. The teaching assistant, while well-meaning, has problems communicating in English, and is only around on certain days of the week. Even if you start to feel that you understand, you are faced with the task of the next chapter's homework, so you really can't afford the luxury of spending yet another evening tackling the same problems.

As he lost some of his footing, Eric noted that it was much harder to "cram" for physics than for literature; hence it was not possible, as undergraduates are wont to do, to let the class "go" for a few days while he concentrated on something else.

The "best class" in Eric's view was one where the professor brought in five or six demonstrations, the results of which were counter-intuitive, and then asked the class to speculate as to why specific results occurred. In this class, there was substantial interchange. It led Eric to wonder whether a class could be designed that was "half lab, half lecture." But even more, he longed for study groups, arranged by the instructor for the class.

The homework problems are hard and take an enormous amount of energy and patience. I think working together might engender an attitude that problems are enjoyable exercises...rather than aggravating stumbling blocks.

Worse yet, on any given day, the class worked on three separate chapters at once.

Take June 13 for example. On this day, the professor answered questions on the homework problems from chapter 6, did some sample problems from chapter 7, gave us a quiz on the material from chapter 6, did some demonstrations pertaining to chapter 7, and began to lecture on chapter 8.

A consequence of the fact that students did their work "in private," Eric thought, was the absence of any opportunity for them to *talk* about the physics they were studying. They seemed inhibited, he observed, even about asking questions. Eric continued to do well on the exams and quizzes and was always surprised, even "shocked" at how low the class average tended to be.

What this means is that there are a good many confused people sitting quietly and not asking questions. This is always the case to some extent in college, but physics seems harder on these people than the humanities. So much is based on what you should have learned the day before, that the course is a bit like a race where if you falter and don't immediately recover, you are sure to go down and be trampled.

The lack of "discussion" continued to fascinate and to bother Eric. He found that when he asked his classmates about what they were studying, they weren't able to "articulate an answer."

I wonder if this is because they lack communication skills or because they haven't yet had the time to reflect on what they have learned, or perhaps because they don't really *know* much about their subject—if knowledge is defined to mean a deep, thoughtful understanding, rather than a superficial ability to regurgitate formulas.

One possible explanation might have been that in a course where answers are so critical, there is an inordinate fear of "making mistakes."

One of the most frustrating things about the class is that the material comes so quickly. Once you stop "making mistakes" and master one chapter, you must move on right away to the next. Almost by definition, you wind up with more wrong answers than right ones. Learning physics becomes a process of making fewer and fewer mistakes, and moving on. There is no time to enjoy the success, no time to use those skills in order to discover more or dig deeper.

Still Eric was able to go deeper. He began to ponder the differences between mathematics and physics.

Today I asked the professor why you figure *work* with a dot product. I got a different answer than I expected. Instead of talking about vectors and scalars, he talked about "what works." I realized that in physics, unlike math, you are much more concerned with getting real and usable figures than in the mathematical integrity of the operation. This is interesting because until this point, I did not really understand the difference between pure math and math as applied to science.

By the last week of class even the professor was "tired," or so he appeared to Eric. The class was but a shadow of what it had been. One-third of the students enrolled had either dropped out or were just not attending anymore. Eric noticed that the ratio of men to women, however, had remained about the same. The professor made numerous mistakes in explanation, and like everyone else, Eric thought, "just wants this class to be over." The "sudden shifts from particles to waves and then from waves to heat and temperature, without a pause, had everyone scrambling."

There are no sad faces on this, the last day of class. No one will miss this chore. No one will say to himself or herself, "I really enjoyed that," or "that was an interesting learning experience." Instead, people will congratulate themselves on having made it, will be happy with their "B" or their "C," and will very soon forget anything pertaining to physics.¹¹

For Eric, the final exam was a compressed version of everything that the course had and had not been, absent the "big picture." Eric had found all four exams in the class "biased toward computation and away from conceptual understanding." He understood that to be able to complete the computations required "some level of conceptual understanding." But that level was "not particularly high," he wrote.

The problems [on exams] seldom required the use of more than one concept or physical principle. Only once were we asked to explain or comment on something rather than complete a calculation.

Eric thought the final, which was cumulative, would be the "... ideal place to tie things up and ask comparative and conceptual questions." Instead, he found that the questions entailed some fill-in-the-blanks definitions with terms found in a list. This caused him to reflect on the course more generally.

We had marched through the chapters, doing the required work, but never digging deeper...I was able to keep myself on track by concentrating on one chapter at a time. But I never really got the idea that the professor had any understanding of how the concepts were related, as he rarely tied together information from more than one chapter. His lectures did not seem to build upon each other, and he gave no indication of a linear movement through a group of concepts...The final then asked the most primary basic questions about only the most important laws of physics. We were not required, at any time, to interrelate concepts or to try and understand the "bigger picture."

¹¹ Research by Hestenes et al confirms the failure of conventional physics instruction to overcome students' naive misconceptions about motion. Ibrahim Abou Halloun and David Hestenes, "The initial knowledge state of college physics students," and "Common sense concepts about motion," *Am. J. Phys.* 53 (11) Nov. 1985, p. 1043, ff.

It was not that the connective tissue was unavailable to the instructor; it was simply not featured. From the beginning of the course, Eric had liked the textbook and felt he had learned best from it. His ability to read through it on his own contributed to his early success in mastering the course. He noticed right away that the daily homework included an approximately equal number of two very different kinds of questions. One kind, for Eric, were only "exercises" and were assigned as homework problems. At one point in his journal he described these as "mathematical in nature and varying in difficulty from easy to nearly impossible." The second kind of questions were of a more "complex, conceptual nature." This latter kind interested Eric very much, but

...[since] these questions were never even mentioned by the instructor after the first day, nobody ever bothered to look at them. I feel that the professor misjudged the value of these questions and missed an opportunity to use them as launching points for discussions of the concepts.

After the final exam, Eric wrote that for him "the greatest stumbling block to understanding" was the lack of identifiable goals and the absence of linkage between concepts. He noted these deficiencies in answering a question we had posed: what makes science hard in general and for students like Eric coming to these disciplines as outsiders? He wrote:

To some extent science is hard because it simply is hard. That is to say, the material to be learned involves a great many concepts, some of which are very counterintuitive. The process of mastering these concepts and being able to demonstrate a computational understanding of actual or theoretical situations requires a great deal of time and devotion. In my experience, this fact is well understood by the students, the professor and the general public. What is not as well understood are the various ways in which this already hard subject matter is made even harder and more frustrating by the pedagogy itself.

He feels that some "skeletal plan" would have helped him enormously to see how each individual property and theory is related to the "big picture." Comparing his introductory physics experience with that of the humanities, he wrote, "A professor who lectures on American literature of the 19th century might oversimplify the various social factors involved in each novel by referring to long-term historical events and trends, but at least his or her students would have some foundation on which to build impressions and judgments of the works."

The other "most difficult aspect" of the course for Eric was the "lack of student involvement" in lectures, and in discussion outside of class.

Simply being "talked at" suited this particular literature student not at all. He attributed his classmates' inability to articulate their subject matter directly to the fact that they got no practice "talking physics" in class.

Finally, he concluded, the "pressure involved in grade wars" goes much too far. He leaves us with the following advice:

If one is truly interested in reforming physics education in particular and science education more generally, de-emphasizing numeric scales of achievement and rethinking the grading curve is certainly one place to start.

Discussion

The course we chose for Eric was a summer session version of the two-semester, calculus-based, introductory physics course which generally serves the "weeding out" role for chemistry, physics, engineering, and at some institutions, premedicine and biology.

The course is standard in its scope and sequence, so standard in fact, that four textbooks together dominate the postsecondary market. (One of them, the one Eric was to use, has more than a 60 percent market share.) Instructors justify their choice of one or another text based on the "quality" of problems and minor variations in the sequence of subject matter. Because it "serves" so many other fields, a course like Eric's will be taken by upwards of 100,000 American college and university students each year, of whom about 1,100 will go on to get the Ph.D. degree in physics. (Another 150,000 study the less rigorous, noncalculus-based introductory physics course.) One structural problem exists at the outset: the professor is training physicists; the students, for a variety of reasons, are taking physics.

When we had Eric's professor read what Eric had written about the course, this disparity was made very explicit. Eric's professor wrote:

I assume that students in 103 are preprofessionals who have already decided on a career in science and are in class to learn problem-solving techniques that will be required of them in their careers...I [also] assume, however less and less, that the students have had some hands-on experience with how things work: clocks, cars, radios...and some experience with, and curiosity about, the physical or natural world. In other words, I assume I can make analogies to get across physical concepts. Students not interested in the physical world have a harder time, since they don't know, and usually don't care, how *things*, cars, bodies, weather, the heavens, work.¹²

¹² Personal communication from the professor to the author.

Eric complained that the "goals" of the course were never clearly articulated, and that the chapters were insufficiently "linked" or made to cohere. This was in part because of the fast pace of the summer session course, but also because the "unity of physics," assumed by the instructor was not explained often enough. Eric yearned for more "conceptual" information (we think he meant "interpretative"), and not just "facts" and the "mechanics" of problem solving. His professor was aiming his course at a different student. The teacher believed that, had he asked for any greater in-depth reasoning in class or on exams, there would have been "sheer panic."¹³ In fact, he was adjusting his course to the needs and the limitations of the students he assumed he was teaching. Eric was asking for a different kind of adjustment, one directed to his intellectual curiosity.

According to Sharon Traweek, an anthropologist who studies the values, training and work styles of high energy physicists, Eric's complaints would not be perceived to be significant by professors whose goal is to train future physicists. From her interviews, she concludes:¹⁴

[Successful] undergraduate physics students must display a high degree of intellectual skill, particularly in analogical [pattern finding] thinking. The students learn from textbooks whose interpretation of physics is not to be challenged; in fact it is not to be seen as interpretation. They learn to devalue past science because it is thought to provide no significant information about the current canon of physics, but they also learn from stories in their textbooks that there is a great gap between the heroes of science and their own limited capacities...

[The emphasis on problem-solving is meant to] show students how to recognize that a new problem is like...familiar problems; in this introduction to the repertoire of soluble problems...the student is taught not induction or deduction but analogic thinking.

There are several ideas to be taken from the Eric experiment. Something besides the traditional problem-solving approach may be needed to excite *new* students to physics. But at least as important as content, if Eric's reactions are typical, will be changes in the "classroom culture" of physical science: more attention to an intellectual overview, more context (even history) in the presentation of physical models, less condescending pedagogy, differently challenging examinations, and, above all, more discussion, more "dissent" (even if artificially constructed), and more "community" in the classroom.

And what of the ten students who "disappeared" from Physics 103a

¹³ *Ibid.*

¹⁴ Sharon Traweek, *Beamtimes and Lifetimes, The World of High Energy Physics*, Cambridge: Harvard University Press, 1988, pp. 74 and 75.

last summer? Eric had no idea whether they had dropped the course or had simply stopped coming to class. In the "old days," a former chairman of the department told me, the course instructor would sign every course drop card, so there was opportunity for an "exit interview" and for some conversation about the course, the student's career goals and his or her alternate plans. Although Eric's professor did see a number of "drops" because of his advertised approachability, today drop-cards are handled bureaucratically by staff. Hence, there is less opportunity for retrieving the failing student or for soliciting students' views about particular courses.

If the science shortfall is to be stemmed at college, many more students should be made to feel welcome and valued, whatever their capacities and degree of commitment to science. The truth is science can be done by people who are not necessarily younger versions of their professors. Despite the emphasis in science on the "heroes" who contributed to what Thomas Kuhn calls "paradigm shifts" in the disciplines,¹⁵ the scientific method was originally promoted by Francis Bacon precisely because it enabled "conventional minds" to do science.¹⁶ Surely there is room in Kuhn's "normal science" for a larger portion of the college population than is currently made to feel deserving and comfortable in science. There is reason to believe many more undergraduates would respond to a differently constructed introductory course.

To an uncertain adolescent, flailing about for something he or she might actually be able to *do* and do well, science offers not just a whole array of interesting and important careers, but a training that, to paraphrase Bacon, enables ordinary people to do extraordinary things. If physicists learned to regard *every one* of those 250,000 introductory physics students—most of them somewhat better than "ordinary"—as having something valuable to contribute and much to gain from science, there might be no science "crisis" at all.

¹⁵ Thomas Kuhn, *The Structure of Scientific Revolutions*, Chicago: University of Chicago Press, 1962.

¹⁶ Francis Bacon, *The New Organon and Related Writings*, ed. Warhat, pp. 353-358, as quoted in Sharon Traweek, *op. cit.*, p. 80.

Jacki and Michele

The themes that emerged out of Eric's encounter with summer school physics were to surface again and again as the project continued. Mindful that summer school is extraordinarily fast-paced and that not all students would be as intellectual or as self-reflective as Eric, we developed a longer project in the fall of 1989 that would place six nonscience students as participant observers in semester-long introductory chemistry and physics courses. While the experiment did not consciously seek out the full range of potential second tier stand-ins, a somewhat diverse group of students responded to our invitation, among them Jacki Raphael and Michele Schoenfelt, graduate students in creative writing and philosophy, respectively.

Like Eric, Jacki and Michele had enrolled in and enjoyed science in high school but, for different reasons, had not pursued science at college. Yet, they rapidly forged ahead in their introductory physics course at the University of Arizona, demonstrating that above average intelligence and motivation, when combined with the power to reflect on what one is learning, contribute substantially to success in this field. While physics itself delighted and fascinated them, they found that the "logic of presentation" and the classroom culture still left much to be desired. The course in which we placed Jacki and Michele, Physics 111a, is an introductory calculus-based physics course, the first of a new four-semester sequence designed to capture potential physics majors immediately upon their arrival as freshmen. Normally, students interested in physics begin their freshman year with college calculus and only start physics in the spring. Fearful of losing them and of breaking the continuity of their high school-college sequence, the department of physics has created Physics 111-112 as an alternate physics sequence. In the first semester, the missing calculus concepts are taught along with mechanics; then three semesters (instead of two semesters) more are spent completing the introductory text.¹ Jacki's calculus skills were rusty but quickly came back. Michele was weaker in calculus and hence had more difficulty with the course.

Jacki

Her professor said of Jacki after she completed the first semester of Newtonian physics, "She could easily have been a physics major, and a

¹ Halliday and Resnick, *Fundamentals of Physics*, Third Edition, *op. cit.*