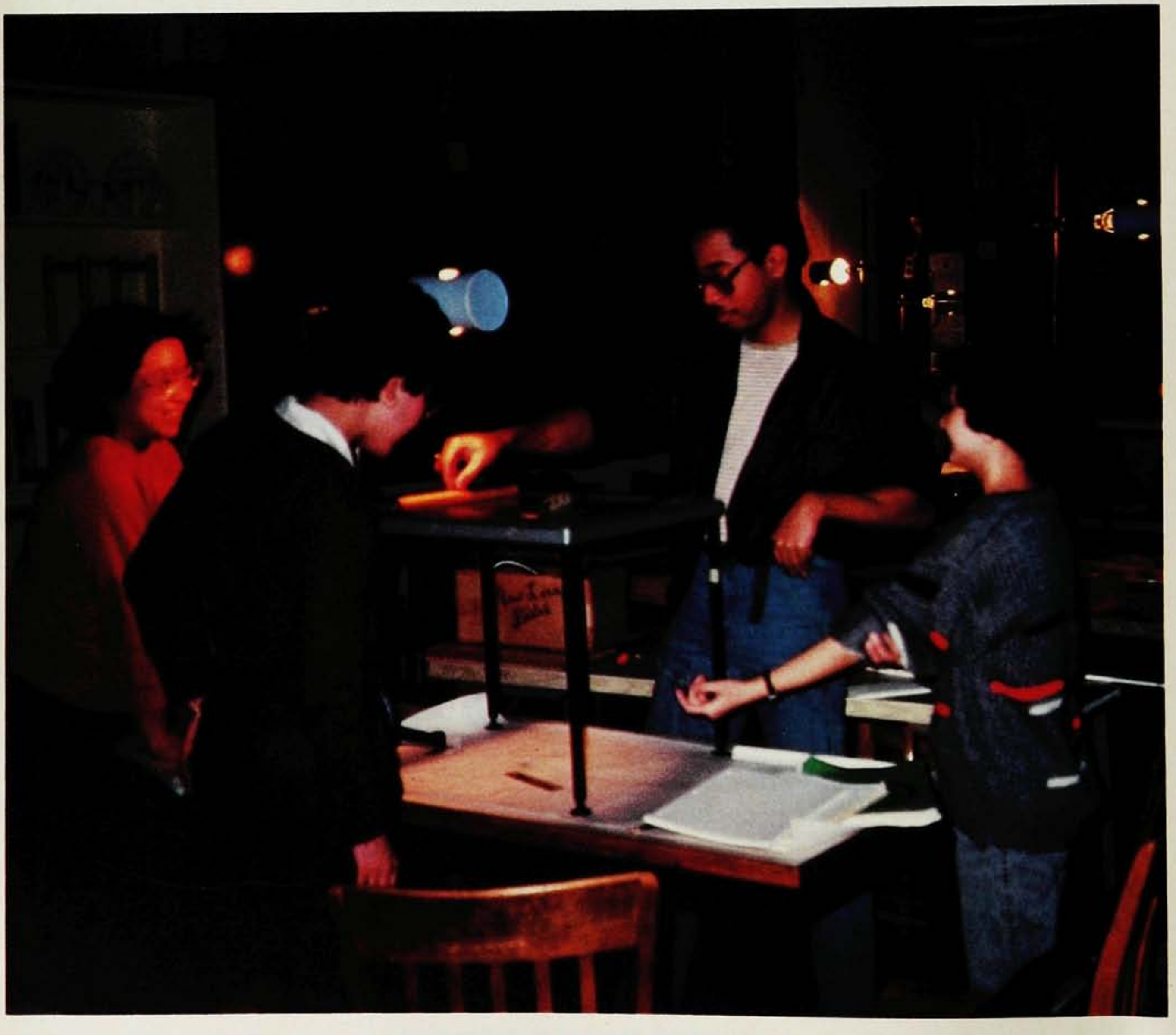
Laboratory-centered physics course at the University of Washington, Seattle. This course helps prepare minority undergraduates for the standard science courses. The emphasis is on connecting physical phenomena with their abstract representations.



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Math anxiety and physics: Some thoughts on learning 'difficult' subjects

It may not be anxiety alone that keeps many undergraduates out of physics, but also factors such as inappropriate learning styles and gaps in experience with the physical world.

Sheila Tobias

For some time now, teachers of physics concerned about the growing gap between the Two Cultures have been, so to speak, stalking the wild humanist. They have set up courses in "physics for poets," recruited nonscience students into seminars to "ready" them for science, and offered physics without the laboratory or calculus. Yet, despite these and other efforts to attract them, liberal-arts majors continue to find ways to avoid physics, even when fulfilling minimum science requirements.

In recent years, systematic research has augmented these pragmatic thrusts. At the University of California at Berkeley, the University of Washington, Carnegie–Mellon University and MIT, physicists, learning psychologists and specialists in artificial intelligence are trying to find out what it is, specifically, that makes learning physics difficult for beginners. As part of that research, investigators determine the different approaches that novices and experts use to solve physics problems, and by way of interviews, they expose students' "persistent Aristotelianisms."

However, students bring more than Aristotelianisms to class. They consider science in general and physics in particular "hard" subjects to learn. As Robert Fuller of the University of Nebraska points out, professors intentionally and unintentionally contribute to this reputation. In a proposal, since funded by Exxon, for AAPT workshops to help teachers develop student confidence in physics, Fuller notes that "Opening lectures often describe the *high* standards maintained by the department, the *firm* math prerequisites, the *poor* grade records of previous classes." Even when they do not make such explicit statements, teachers convey the message that physics is a particularly difficult subject, says Fuller, and this damages student confidence.

How significant, then, is apprehension in discouraging nonscience undergraduates from attempting physics? Might the anxiety-reduction techniques that proved useful in treating fear of mathematics work for the physics student? While it remains to be seen whether the sources of physics anxiety and math anxiety are the same, one thing is clear to someone who has dealt with fear of mathematics in college-age students: The two have similar manifestations. Hence, even though the discussion in the first half of this article focuses on obstacles to learning mathematics, I think readers will find that it rings true for physics as well.

A number of physics educators are attempting to treat physics avoidance and even physics anxiety in a variety of special programs. In the second half of this article, I will report on a few of those innovations and try to evaluate them in terms of some theory.

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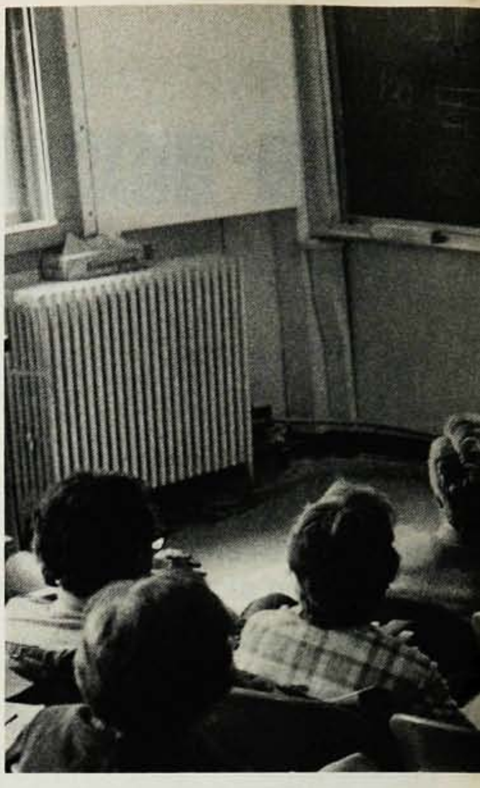
Avoidance as a form of revolt

I was a feminist before I became concerned with mathematics anxiety. Hence my interest was initially piqued by the particular problems women and girls face in learning mathematics at all levels. From the outset my focus was on the learning, not on the teaching, of what is reputed to be an inherently difficult subject. Unlike educators, who traditionally focus on pedagogy and curriculum, I was interested in the psychological and ideological barriers to learning. The challenge here was to try to find out whether what learners think about themselves in relation to the subject might have some bearing on their "ability," as measured by traditional means such as standardized tests.

The phenomenon was longstanding, but it only became a "problem" when people began to try to solve it: Women, more than men, girls more than boys, avoid mathematics and fields that presume mathematics training or skills. Undertaking a now much-quoted survey of the entering class at the University of California, Berkeley, sociologist Lucy Sells broke new ground in 1972 and reported[1] that 57% of the entering males had taken the fourth year of high-school mathematics and only 8% of the entering females had done the same. While one might argue that students who had three years of well-taught high-school mathematics are prepared for calculus, physics and engineering, Sells's students—especially the women—didn't *think* they were. Hence, Sells could conclude that 92% of the entering females had cut themselves off from three-quarters of the Berkeley options, even before they started college, because of what she termed "mathematics avoidance."

Defined as math avoidance, the phenomenon became a guidance problem, and the next step could have been

Experiment to find out why physics teaching often fails to reach liberal-arts students. Here physicist Mel Shochet gives a lecture on relativity to a group of University of Chicago deans and faculty members from the humanities and social sciences. Physics department chairman Hellmut Fritzsche and the author designed the experiment, and are now receiving feedback from their learned students on such issues as language barriers, the lecture mode of presentation and the effect of previously formed anxieties. (University of Chicago photograph by Patricia Evans.)



to give it over entirely to counselors willing to work against the widespread, popular notion that mathematics is a "male domain." However, as I discovered through interviews with "math avoiders" at Wesleyan University in Connecticut, able liberal-arts undergraduates do not simply avoid mathematics—they roundly reject it.

Their reasons sound the same, whether their disaffection occurred during elementary school, in junior high school at the first bite of algebra, or at the very prospect of taking calculus, even after three or four years of high-school mathematics. Confidence in mathematics, especially among females, is not a necessary outcome of exposure to the subject or even of achievement in it.

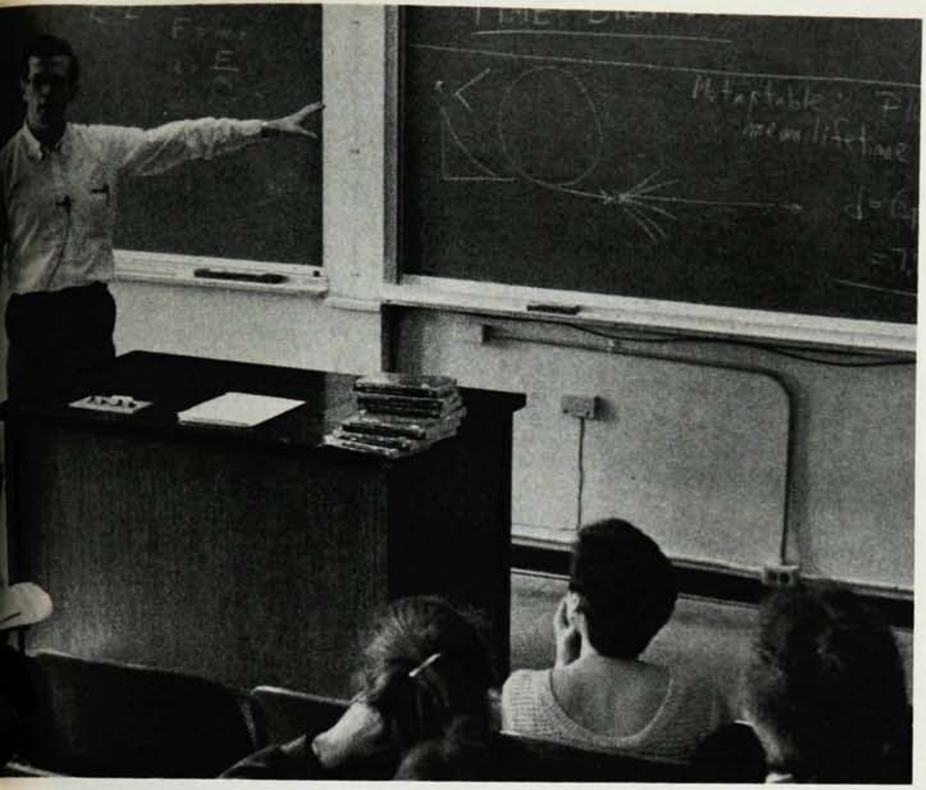
Instead, what appears to link students of very diverse mathematical "ability" is a collection of what might be called ideological beliefs or prejudices about the subject. Students' early experiences with mathematics typically give them false impressions not only of the nature of the subject, but also, and more perniciously, of the kinds of skills required to master it. They think, for example, that speed is more important than persistence. Even more humbling, most come away from their exposure to mathematics believing they do not have the *sine qua non* of mathematics success, namely, a "mathematical mind."

When the students that I interviewed—particularly the women students—decided to stop taking mathematics, they explained this in terms of their feelings: They felt helpless and out of control in confronting mathematics; they were easily bewildered and found themselves humiliated in class; they were uneasy solving or analyzing problems under time pressure, and they had become distrustful of intuitive ideas that had not been formally introduced in the text. Because of all this, the students felt compelled to memorize solutions to individual problems.

Clinical findings. A Wesleyan "math clinic," established under a Federal grant, made a systematic assessment of what these students had learned before coming to college and found they had not been taught the *coping skills* they felt they needed most—not what to do in a mechanical sort of way, but what to do when they forget or realize that they never really learned how to solve particular problems. These students had wrongly taken away from their high-school teachers the notions that people able in mathematics don't make false starts or fail, that solutions are usually "obvious" and that problem-solving is always "fun." Thus when the students experienced the mathematics classroom as alienating, anxiety-producing and authoritarian, they did not believe their teachers could help them deal with their feelings because their teachers were "able" and they simply were not.

From these interviews and impressions, the staff of the math clinic restated the problem one more time as not residing in a particular pedagogy, not even more generally in "poor teaching," but rather in student self-perceptions and in a belief system that rests on the presumptions that either one is mathematical or one is not.

The first intervention, then, was psychologically oriented. Wesleyan initiated a math anxiety clinic staffed by mathematics instructors and psychological counselors of both sexes, and not in the sex-stereotyped roles of male math instructors and female counselors. The clinic was advertised as a place where "anxious" and "avoidant" students could come to talk about mathematics, take noncredit review and refresher classes in the subject, practice self-observation and do exercises designed to reconstruct feelings of confidence and control. The explicit goal was to get students who had dropped out of mathematics to return to standard college-level math by way of a series of new precalculus courses



offered by the mathematics department, but not before they had also had some "assertiveness training" (see the "Learning Bill of Rights" on page 68) to increase their classroom participation.

In its first three years, the Wesleyan University Math Clinic treated 600 students out of a total undergraduate student body of 2300, only half of whom were studying mathematics or other quantitative fields. The system, later described in a book[2] and a series of how-to manuals published by the Washington School of Psychiatry, incorporated the following:

▶ The "math autobiography," which, discussed individually or in groups, is intended to give students as much information as possible about what had happened to them in learning math when young.

▶ The "divided-page exercise," where students learn how to articulate and to keep a record of their feelings and thoughts—including their "irrelevant" mathematical ideas—on one side of a page while doing their problem-solving on the other; this involves a systematic self-observation and monitoring of feelings where students note thoughts such as "This is just the kind of problem I can never solve."

▶ Relaxation or desensitization, which students use to deal with self-imposed or classroom-imposed tension.

▶ Assertiveness training, which students use to regain control of their learning pace and learning style.

"What is making this problem difficult for me?" a student is trained to write down on the left side of his or her homework page before quitting the problem, and following that, "What could I do to make this problem easier for myself?" In terms of ideological re-education or deprogramming, the system for overcoming math anxiety urges students to take on faith that, at least at the levels where they are working, one does not require a mathematical gift or special mathematical talent, just general intelligence and diligent application.

The problem, as finally formulated by the clinic staff, is not merely student lack of confidence, although this is almost always a symptom. Rather, students encounter mathematics as a rigid subject presented to them in an authoritarian way. Because they are actually powerless to alter either the sequence of the material or the "rules" of the game, and are not even free, as they see it, to consult another textbook for clarification, their alienation can be interpreted as real, not imagined; their fear an age-appropriate expression of anger; their apathy and avoidance, even in some cases their anxiety itself, a form of revolt!

Mathematicians and physicists may be surprised that students do not on their own come to realize that these subjects are precisely a means of gaining control over complex and inchoate subject matter. On the contrary, students' perceived lack of control, even more than their pure anxiety, becomes the centerpiece of the clinical intervention.

Over the last decade, many undergraduate and continuing-education programs have established clinical approaches to the reduction of mathematics anxiety and avoidance. Evaluation of these innovations has not been systematic, but program directors report that the programs that succeed are the ones that work with otherwise successful students whose only disabilities are in mathematics. Students who have more generalized trouble in college do not respond. Women and minority students are attracted to these programs and benefit considerably from them. Program directors see changes in student attitudes toward quantitative material and a reduction in anxiety. Passive students become more assertive in class. Failing students succeed.[3]

Doing physics

What about physics, another "difficult" subject which, according to Sells, promises to become "the next critical occupational filter" for minorities and women? Could underenrollment in university-level physics be classified as "willful avoidance" as in mathematics? Could anxiety be a key factor? And if so, can one speak of and treat "physics anxiety" as separate from "math anxiety," "lab anxiety" or a more general form of science avoidance?

Certain similarities, but also certain differences, are immediately obvious. First, among physics students or potential physics students there appear to be two non-overlapping populations: those whose anxiety is the result of exposure to physics courses and those whose anxiety or, better stated, apprehension, keeps them from trying physics even once. In the case of math, the anxiety is usually the result of exposure to math courses, whether the student is successful or not. Students who have failed at mathematics, and students who have succeeded but without gaining confidence, manifest similar tension in anticipation of defeat. The dropout rate in mathematics is as much a problem as underenrollment.

Not so, it appears, in physics. Fewer students elect physics as part of a general education program than take mathematics, to be sure, but once students enroll in physics, their dropout rate does not normally exceed the 20–25% of other rigorous courses. Hence, either the preselection process in physics is more effective in weeding out the timorous and the underprepared or the anxiety-by-doing in physics is somewhat less of a problem.

Second, newcomers to science, and to physics in particular, need to bring with them a certain amount of experience—not academic experience, but a kind of informal training, which is not available to all students equally at home or at play. While women and minorities are particularly needy in this regard, white and male students who bring with them to college unexamined assumptions about the physical world need help too. Good science teachers like to draw on students' physical experiences, and if these are limited or if students haven't thought about them, there is a problem.

High-school physics student attending "physics day" at an amusement park. Rolling Hills (California) High School physics teacher John McGehee founded this annual motivational and educational event. A group of ten Southern California high-school physics teachers has developed 130 questions and problems to be completed by each physics student at the park. Students use equipment such as stopwatches and accelerometers to answer questions involving quantities such as velocity, friction and centripetal force. The student pictured here is using a protractor, drinking straw and hanging weight to measure the angle to the top of a roller coaster that features a 360° vertical loop. (Six Flags Magic Mountain photograph by Jean Drummond.)

In addition to needing help with basic physical principles, nonscience students need to be taught how learning takes place on the other side of the campus. Liberal-arts students are unprepared, for example, to use the science textbook as a referent. They are surprised to find that their science-student peers do not, for example, read their assigned chapter first; instead, they do their reading after they have tried to solve the problems at the end of the chapter. In fact, some of their teachers never read the text! The point is that the textbook has a different function in science than in literature. Hence, just as in math-anxiety reduction, where time is spent teaching students how to "read mathematics," so, too, some attention to "reading science" may have to be part of a readiness program.

For liberal-arts students attempting science, problem solving is both an ideological barrier and a skill difficulty. These students do not understand that problem solving in physics, for example, is not merely a test of what has been learned through reading or listening to lectures or a proof of work done, but is, instead, the major technique for learning new material. Indeed, liberal-arts students are forever needing to be shaken loose of their assumption that having read or even memorized the material, they are supposed to understand it. The fact that they can't do the problems makes them feel even more confused than insecure. What they do not appreciate at first is that understanding in physics courses is defined operationally: It is being able to do the problems. Knowing the history, the definitions, even the explanations of the unit under study is no substitute—and may not even be relevant—to the kind of performance expected.

Important among the ideological issues is the elitism of many practitioners of physics, including their too-frequent preference for students, especially male students, who think like they do. Fuller's workshops for university and high-school physics teachers deal with elitism and suggest that teachers "try to find the hidden physicist in every student." Indeed, anyone interested in expanding the population of students who will voluntarily and enthusiastically study physics must begin to rethink questions such as these: How much "talent" beyond general intelligence, diligence and motivation must a student have to study physics? Is it really probable that when professional opportunities are truly equal, as they must become in the next decades, American physicists will continue to be overwhelmingly male, white and firstborn?

Ongoing projects

The physics-teaching program that most closely parallels the work done on math anxiety is at Loyola University in Chicago. Under the aegis of the Loyola Counseling Center, physicist Jeffry Mallow established in 1978 a "science anxiety clinic" and later wrote the book *Science Anxiety* and several articles about his work.[4]

The clinic at Loyola is a noncredit offering open both to students having difficulty in science classes and to students altogether too fearful to enroll. In weekly 90-minute sessions, the seven-week program gives students help in

- ▶ developing basic science skills
- ▶ replacing negative self-statements with objective and rational ones
- ▶ training in relaxation and desensitization.

The results, according to Mallow, are measurable changes in student attitudes, behavior, willingness to study and ability to succeed in science.

Working with a psychological counselor, Mallow found that students bring debilitating preconceptions about physics and about their own science abilities to the classroom. "The mythology of how difficult physics is permeates the student population at college," Mallow told me recently. This view of physics is strong, even among students with no exposure to the subject in high school. One reason there are many fewer science anxiety clinics than math anxiety clinics, says Mallow, is that "colleges have invented watered-down courses in science, allowing students to avoid real science without appearing to do so—and with the complicity of the school itself."

Even more insightful is Mallow's observation that students who do poorly in physics may not be cognitively immature, as some of their instructors have claimed after seeing them behave as if locked into a concrete reasoning stage and ill-equipped mentally to deal with abstractions. Mallow suggests that anxious students *retreat* to these concrete-reasoning behaviors, although they have actually grown beyond them, whenever they feel nervous in class or out of control.

At the University of Washington, Seattle, the Physics Education Group is investigating difficulties students encounter in studying physics, and is developing instructional materials to address these difficulties. (See PHYSICS TODAY, July 1984, page 24.) Under the direction of physicist Lillian McDermott, this research and curriculum development program includes students enrolled in the standard introductory physics series as well as two other special populations: minority undergraduates aspiring to science-related careers, and precollege teachers, both future and practicing.

In a two-year program to improve the performance of minority undergraduates in the standard science courses, the group teaches a series of courses that use laboratory experiences to develop basic concepts and scientific reasoning skills.[5] The emphasis is on helping students make explicit connections between physical phenomena, scientific concepts and their algebraic and graphic representations. The program provides a supportive environment in which students actively participate in discussions with the staff and one another. Through these interactions the students gain confidence in their ability to use their own reasoning to solve problems.

While McDermott and her team are doing what at first glance might appear to be review, their program is not remedial in any operational sense: Students are not being retaught techniques or concepts that they have been taught before. On the contrary, the very point McDermott seems to be making (at least as it appears to someone who has worked with the math-impaired) is that some science students have to be taught explicitly what their experience and their background did not automatically provide. Pedagogically and politically it is more appropriate to consider this kind of prephysics

SIDNEY HARRIS

"Actually I started out in quantum mechanics, but somewhere along the way I took a wrong turn."

Students and teacher Robert Fuller in a physics course for nonscience undergraduates at the University of Nebraska. Here the students are noting the temperature during a cooling-rate experiment. The course is designed to develop reasoning ability. (University of Nebraska photograph.)

course to provide "readiness" or "compensation" rather than "review." Some of the minority students in the University of Washington program have gone on to out-perform nonminority students in the standard introductory physics series.

Experience in visualizing spatial relations and experience with what I call "street mathematics" are factors that come up in discussions of the problems that women have in mathematics. Clearly this kind of experience also plays an important role in students' readiness for physics. Volumes and masses are often an important part of a boy's play with toys such as building blocks and construction sets, but not of a girl's play with toys such as dolls, dollhouses and make-up kits. "Orienteering" is a Boy Scout activity; fractions readily become ratios when translating between batting averages and hits for times at bat; and turns of the bicycle wheel are comprehensible as a function of turns of the pedal. Together these kinds of activities anticipate more complex ideas in algebra, geometry and physics. There is no reason why we cannot work to compensate students for any missing experience, and even teach them spatial relations.

Physics 'immersion'

To get at some other aspects of "readiness" for physics, two Hampshire College physics instructors and I organized a one-day physics workout for self-defined physics avoiders, in March 1984. Hampshire College, in Amherst, Massachusetts, is an innovative undergraduate institution that encourages interdisciplinary work by organizing its faculty into broad groups called "schools" instead of departments. This is meant in part to encourage nonscience majors to try science. Still, large numbers of Hampshire students do not take physical science.

We decided to have an "immersion" in physics in the belief that an exhausting workout might loosen up students' resistance to physics and shake up their preconceptions about their lack of physics "talent." Because their anxiety was not grounded in any past negative classroom experience with physics—they had never studied physics before—the approach had to deal with both ignorance of physics and straightforward physics apprehension.

It is worth describing the immersion in some detail, as it illustrates some similarities and differences between math anxiety and physics apprehension.

Experimentalist Frederick Wirth designed the worksheet, an adaptation of a unit in Arnold Arons's *The Various Language: An Inquiry Approach to the Physical Sciences*.[6] Theorist Herbert Bernstein designed the instructional strategy.[7] The "missing experience" that this immersion was to fill in was time spent playing around with light bulbs and batteries. The hoped-for result was the discovery of the properties of parallel and series circuits and a feeling for Ohm's law.

Working in pairs, the students tried to arrange wires, batteries and bulbs to get various results called for in the worksheet. The worksheet stressed the usefulness of drawing diagrams and taking careful notes on the trials. No one in the group had ever made a bulb light before, so the presumption about missed experience was correct. Each pair of students eventually got the bulb to light, outlined the conditions under which one could obtain more or less brightness, and discovered that the amount of current was not so much a function of the number of bulbs as of the architecture (their word) of their wiring.

Without imposing a text or time pressure, the immersion gave students the "permission and protection" Mallow writes about, allowing them to talk through their experiments. Nonscience students want to conceptualize phenomena, even physical phenomena, in words. Thus their understanding emerged through their articulation and rearticulation of what they thought was going on as they worked.

We did not teach the students any formal notation, so many began their note-taking with narrative sentences to describe each trial. However, by the end of the first two hours, even the most "literary" among them had switched, for reasons of speed and efficiency, to shorter sentences, phrases, and even letter-codes and symbols of their own devising. Their initial drawings, in time, became cartoons. Slowly they were beginning to express a need for circuit diagrams.

Some time later, during a lecture that capped the immersion, one student observed with evident excitement that a precisely drawn circuit diagram could be used in place of additional trials to predict the feasibility of a

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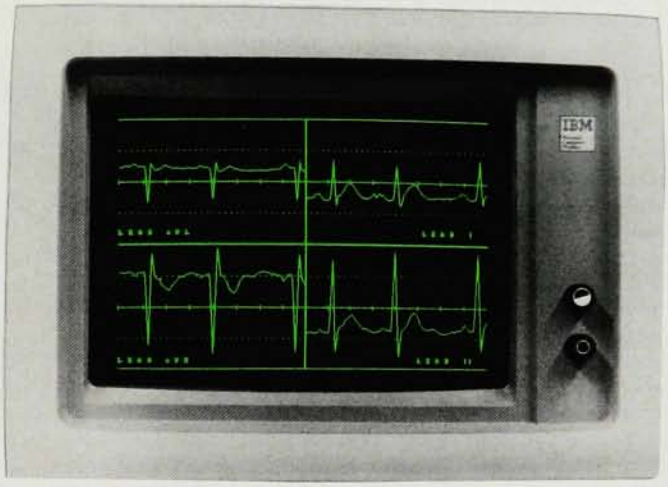

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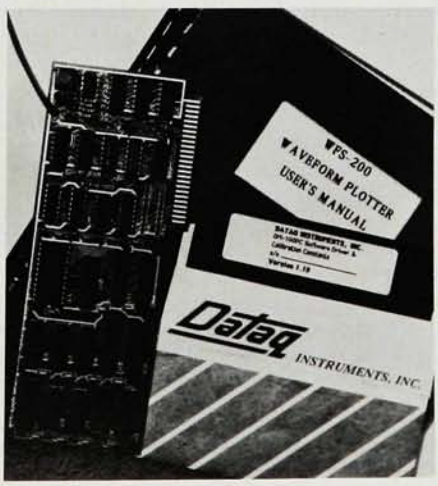

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The learning bill of rights

I have the right to learn at my own pace and not feel put down or stupid if I am slower than someone else.

I have the right to ask whatever questions I have.

I have the right to need extra help.

I have the right to ask a teacher or TA for help.

I have the right to say I don't understand.

I have the right not to understand.

I have the right to feel good about myself regardless of my abilities in a particular subject.

I have the right not to base my self-worth on my skills in a particular subject.

I have the right to view myself as capable of learning any subject.

I have the right to evaluate my instructors and my textbooks.

I have the right to relax.

I have the right to be treated as a competent adult.

I have the right to dislike a subject.

I have the right to define success in my own terms.

Adapted from Sandra L. Davis's Math Anxiety Bill of Rights, which appears in reference 2.

certain architecture, the relative amount of current and the likelihood of a short circuit. Only at the end of the day, when Ohm's law had been explained, did the instructors establish the significance of quantitative relationships. The next step would have been to assign group problem-solving.

None of the students found the experience in itself anxiety-enhancing. Perhaps this is because they were allowed to wander freely in the laboratory or because they could write their own "text" as they went along, or perhaps it was because they were permitted to "talk physics" before having to "do physics" (the problem solving). The experiment was too meager and the sample too small for generalizations, but physics educators would do well to find out more about preferences and learning styles in physics, as was done for mathematics.

Articulate test group

One obvious way to ascertain why otherwise accomplished and confident learners think physics is going to be difficult is to observe at close range a population known to be able and articulate but naive in regard to physics. Such a population exists on every campus: professors of humanities, social sciences and the arts who have demonstrated skill in their own fields of language, philosophy, history, law and politics, but whose background may be entirely lacking in science. A well-designed experiment using such local scholars as learners and their science colleagues as instructors should provide much insight into how nonscience students perceive the subject and in what sequences and by means of what kinds of problems they would learn more efficiently.

Such a physics-teaching experiment took place recently at the University of Chicago.[8] The results are not in yet, but the hope is that instructors are better than students at articulating difficulties, and that they can evaluate instructional strategies for minds very much like their own. If one goal of physics education is to reach those who consider themselves "outside" science, then this kind of solicitation of peer perspectives could be an interesting first step in the process of finding out what makes science difficult (and a not-so-subtle way of getting liberal-arts faculty to recommend physics as part of students' general education).

During the past decade, mathematics educators have become significantly more committed to the goal of engaging more students—and different students—in learning mathematics, and most have become a little more skeptical than they used to be of the argument that gender and racial or even ethnic differences are at the root of mathematical ability.[9] However, mathematicians, for the most part, still consider their subject to be particularly difficult, mathematical talent to be natural rather than learned, and themselves, therefore, to constitute an elite. So, while gender and racial gaps in mathematics achievement may be narrowing—certainly a positive change—there has been little change in mainstream mathematics in terms of presumptions and bias.

Physics educators have a chance to improve both!

* * *

I thank Herbert Bernstein and Fred Wirth for their assistance in describing the physics immersion experiment at Hampshire College.

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