We can do better: A Report on Some Teaching Innovations.

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All of us are missionaries for physics. We are well aware of the many obstacles, both external and internal, to this work, but we don't have a great record of finding new and effective ways to deal with them. At Rutgers University we are trying to address several of the major problem areas: the declining number of physics majors, the dissatisfaction with the introductory courses, the barrier that physics courses represent for students who are not well prepared, the often marginal support system that we provide for our students, and the neglect of these problems by many members of the faculty.

We have the normal physics major curriculum with standard courses and provision for honors projects. It provides excellent preparation for graduate school. If this "professional" major were our only one, we would have of the order of ten graduates per year, as is true for comparable institutions. Some decades ago we added the "general" major, with a less demanding curriculum, based on the premise that we can provide substantive science-based education to students who do not intend to pursue a research career in physics.[1]

We instituted two new full-year courses to follow the introductory course and a year of calculus. One *is Advanced General Physics,* which includes parts of the normal junior and senior courses, but at a reduced level of intensity and mathematical sophistication. The course is "self-paced" in order to provide the flexibility to accommodate students with a wide variety of backgrounds. The other is a laboratory course with a substantial amount of computer use. We also require two further semesters in physics, which can be chosen from among our regular advanced courses, but can also be special courses (*Physics of Sound, Physics of Modern Devices*), which are less rigorous and problem-oriented. That leaves a block of time equivalent to six semester-courses that is used for a "coherent concentration" of courses, flexibly chosen in consultation with an advisor in the Department. The program facilitates double majors, and is used by pre-med and pre-law students.

Do the students learn everything that we want them to know? No – but then this is true also for most of our other students.

We also have a 5-year program in conjunction with the College of Engineering, and an applied physics major. This puts us in the rarified range of 45 graduating seniors this year. In the fall we are starting a major in astrophysics, a subject with the added feature that it seems to attract a much greater fraction of women students.

We have about 2500 students at any one time in our introductory courses. The traditional system of lecture (one-way and impersonal), recitation (problem drill), and laboratory (cookbook) is widely vilified, but only rarely reformed. We are trying to change each of these parts, as well as the interaction between them.

The lectures can now be more interactive, with the help of a student-response system [2], which allows the students to answer questions anonymously (or not), with immediate feedback. In my experience there is nothing that engenders discussion in a large class to the same extent. The questions are those that the students have just studied, and they have thought about them moments ago. When they see that the choices that they have made are controversial, they are eager to discuss them.

Modern technology allows homework to be computer-based [3]. This frees the recitation period from its former burden, and allows it to be used more creatively, for more life-like problems, group problem solving, minilabs [4], or other activities that reinforce or extend the material currently being studied. Similarly the laboratory, while it can take many forms, can be a place not only for "procedures" but for real learning. Above all, the different components of the course need to be closely coordinated. For each week there is a program, and during this time each meeting concentrates on the same topic, each supporting the others, each contributing to the student's engagement with that part of the subject that forms the week's program.

The reform of the courses is a work-in-progress, only gradually permeating the culture of the Department. The ideas described here were pioneered in our "extended" courses for at-risk students [5,6]. These are not remedial courses. Rather they provide more time (and commensurate credit), smaller classes, and other features that make them more personal and more student-friendly. Credit is given for every activity, including but not limited to tests and a final exam. (Yes, a minute fraction of the

grade is given for attendance, and it has a disproportionate effect!) Each course has a coordinator, who gets to know the students and is available for a variety of support activities, and may or may not also be the lecturer. One of these courses is parallel to our first-year engineering course, the other to the course taken by biology students, pre-meds, and other science majors. One measure of success is that in their second year the engineering students from the extended course are in the regular course, with all the tests that the other students take, and their average grade is comparable to that of the rest of the class. The new courses have made it possible for students to enter the engineering and health professions, who would, to a large extent, have been prevented from doing so in their absence.

An essential role is played by the teaching assistants. Weekly meetings of all of the personnel in a course are the primary venue for coordination of activities, and for making the assistants active participants and vital colleagues.

We have a Math and Science Learning Center, which started as the Physics Learning Center [7]. It is a place for tutoring, review sessions, help and office hours, and some classes. Videotapes and old exams are available. Unlike most such centers it has museum-quality demonstration equipment that can be used by anyone, and as a result there is a lively atmosphere that can not be equaled by having only tables and blackboards. This equipment also forms the basis for some of the laboratory activities that are regularly assigned in our courses.

Does it take more time and effort to teach in these new ways? Perhaps. But whatever we do, if we are committed to it, if we want to do it well, requires that we give of ourselves, to the best of our ability. In return there is the much greater satisfaction, not only for the students, but also for us, the instructors.

Does it take more resources? It depends on how much you want to do. Today the need for such resources is widely recognized, and administrators, government agencies, and foundations are, more than ever (and often more than the departments), ready to support educational activities and educational reforms. It also depends on how you measure the cost. The cost per successful student is more appropriate than the more usual cost per entering student, if you wish to recognize a greater success rate. [5]

What about the old cynical view that effort spent on teaching is not rewarded? I think it is wrong. In all cases that I know of, vital and creative involvement in teaching activities has led to recognition and professional advancement. Sometimes the recognition has come slowly, and it is certainly not enough to say that the private and personal rewards are great. We need to provide more support, moral, professional, and financial for those who go beyond the old routine methods and who contribute with their time and their thoughts to new and more successful ways to teach. The atmosphere for acceptance of reform is now better than it has been at many times in the past. Our efforts have to continue, for the sake of the students, and for our own. We can do better!

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