The Physics Program at Reed College

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Spin-Up Meeting—Cal Poly San Luis Obispo

June 26, 2010

1 Introduction

Reed is a small Liberal Arts college in Portland, Oregon. It boasts a strong program the Humanities and Social Sciences, as well as the Sciences. What is most striking for our present purposes is that the number of physics majors is unusually high, in comparison both to other institutions and to the other sciences at Reed. Out of a total enrollment of 1300, we have graduated an average of 18 physics majors a year, over the last two decades. In this respect Physics is larger than Chemistry and Math, and about half the size of Biology (which at most institutions is bloated by PreMeds and a sentimental fondness for fuzzy animals).

I wish I could tell you *why* our enrollments are so gratifyingly large. To a large extent I think it is something that feeds on itself. Physics is prestigious at Reed, and we seem to get more than our share of the liveliest students. The institution as a whole tends to attract a hardworking and academically dedicated student body (I sometimes think the most important characteristic of Reed is the absence of fraternities and football). But if I cannot give you a magic formula for success, I can at least describe our program, and point to some features that are unusual and perhaps exportable.

2 Curriculum

At Reed the first two years are very traditional (not to say old-fashioned), dominated by the required required Freshman Humanities course, which concentrates on the ancient Greeks and Romans. The typical physics major takes one physics course and one math course each semester. The last two years, by contrast, are heavily focused in the major. Most physics majors take three physics courses each term (four courses is the standard load), and (with electives) it is not uncommon for a serious student to take nothing but physics, in some semesters. I myself think this is a mistake. After all, they chose to attend a liberal arts college—they can study elementary particles in graduate school, but this is probably their last opportunity to take French history or Russian literature.

	Fall	Spring
Freshman	Mechanics	Electricity/Magnetism
Sophomore	Oscillations/Waves	"Modern"
Junior	Classical I Electrodynamics I Advanced Lab	Quantum I Electrodynamics II Advanced Lab
Senior	Classical II (GR) Thermal Thesis	Quantum II (elective) Thesis
Electives	Astrophysics Solid State Computation	Biophysics Optics Elementary Particles

2.1 Lower Division

The first-year course is a traditional calculus-based Introduction. We are currently using Giancoli's book, but in the past we have often used Halliday and Resnick. The 110 students or so attend three lectures a week, one small "conference" section (15 students) and a lab. The latter are quite standard, though the data acquisition is now mostly by computer (something about which I personally have mixed feelings). In this country everyone seems to agree about the basic structure and content of the freshman course, but we all go our separate ways in the sophomore year. At Reed the fall semester is ostensibly devoted to oscillations and waves (we often use French's book), but the hidden agenda is mathematical methods, at the level of Boas. Damped, driven, and coupled oscillators offer a perfect vehicle for introducing differential equations, complex variables, and linear algebra, while waves are a natural context for separation-of-variables and Fourier analysis. The spring semester is "modern physics": when I teach it I spend two or three weeks each on classical thermodynamics, special relativity, quantum mechanics, elementary particles, and statistical mechanics (I like to put thermo at the beginning and stat mech at the end to emphasize their radically different approach to similar material). In the lab two quarters are devoted to electronics, from simple DC circuits to Operational Amplifiers, one quarter is a grab-bag of classic experiments (Millikan's oil drop, the photoelectric effect, e/m, the speed of light, Michelson interferometers, etc.). The remaining quarter (which we usually teach first) is not really a lab at all, but an introduction to Mathematica. This has been astonishingly successful—perhaps too much so. Many of our majors do all their subsequent homework in Mathematica, and a few of them (this is the bad part) get to the point where they use Mathematica to evaluate simple integrals they could have done more quickly by hand.

2.2 Upper Division

In their last two years most physics majors take two semesters of Electrodynamics, two of Classical Mechanics, two of Quantum Mechanics, and two of

"Advanced Lab". This is luxurious when you are teaching Electrodynamics or Quantum; I think it is overkill in the case of Classical Mechanics, and in recent years this course has usually been devoted instead to General Relativity. You'll notice that the two semesters of Classical and Quantum are split between the junior and senior years; this is to ensure that students embarking on the senior thesis have at least *some* exposure to both fields. I'm embarrassed to say that Thermal physics is not required for the major, but most serious students take it, either in the junior or senior year.

Finally, there are a number of "electives" we offer on a two-year rotation; these are taken by juniors or seniors, and by an occasional precocious sophomore.

3 Special Features

In addition to our unusually rich (for a liberal arts college) upper-division curriculum, there are several special features of the Reed physics program that are worth mentioning.

3.1 The Junior Qual

Every Reed student must pass a "Junior Qualifying Exam" in his or her major discipline, designed to certify that the student is ready to embark on a senior thesis. In some departments this has become little more than a formality, but in Physics we take it very seriously, and every year some students fail it (if they do so twice, they must switch to a different major—for us this almost always means Mathematics). It is a comprehensive exam on the first two (actually, two and a half) years of physics, administered in February. Frankly, we are always disappointed in the results, and I myself think it is as much a psychological challenge as a test of knowledge. Most exams at Reed are the open-book take-home variety, and our students have little experience with four-hour in-class exams with no notes or references allowed. They study hard for the qual, and some of them are terrorized by it. But I have been amazed by the number of alumni who report back from graduate school that the junior qual was one of their most useful experiences, after which their graduate exams were much less daunting. And it does help to alert us to students who may have passed their required courses but who are headed for real trouble on the senior thesis. So even if it is not a perfect measure, I am persuaded that it is a worth-while exercise.

3.2 Summer Internships

Portland is surprisingly isolated from the "real world" of physics—I believe it may be the only major city in the country without a full-scale research university. And our department is small (6 FTE's). Our most serious defect, in my opinion, is that we cannot offer our students the experience of working in a large modern research lab, with graduate students and post-docs, and fancy

expensive equipment. In compensation, we strongly encourage all our majors to apply for summer internships—at SLAC, Fermilab, CERN, Aricebo, and universities across the country. Essentially all of our majors enjoy at least one internship, and many do two or even three, in the course of their undergraduate years. Over the years we have built up good connections with national labs and REU programs, so we can practically guarantee our students (except the international ones) admission to such a program.

This is controversial, both at Reed and at other institutions. Our Chemistry department thinks we are irresponsible to send our students off-campus in the summer, and when I was visiting Grinnell College (talk about isolated!) a few years ago I was surprised to learn that the institution works hard to keep the students on campus. I don't understand. Of course, some of our students work in faculty labs, but I'm sorry: this is no substitute for a summer at Stanford or Cornell.

3.3 The Senior Thesis

At Reed every senior writes a thesis. This has been true since the founding of the College a hundred years ago. The thesis is formally equivalent to two regular courses, though most students spend considerably more time on it, and it is for everyone the principle defining characteristic of a Reed education. It is extremely costly in faculty time, and it would certainly not work everywhere. When I first got to Reed, I thought it was crazy. But I have changed my mind. Not that every thesis is a resounding success—far from it. But I cannot predict in advance which students will rise to the occasion, and which (luckily, a much smaller number) will fall flat. I have had students who were lackluster in the classroom, but took the ball and ran when presented with the challenge of an original research project. And occasionally I have had a student who was brilliant at solving textbook problems, but completely lost when confronted by a problem that called for real independence and creativity. Either way, they learn a lot about themselves, and their prospects for success as scientists.

It is fashionable nowadays to extol the virtues of undergraduate research, and I'm all for it. But I must say that what some people call research is not at all what I mean by the word. Several years ago I was at a conference for theorists from small colleges; at one point we were discussing undergraduate research, and somebody mentioned that his specialty was simply inaccessible to his students. He occasionally hired assistants to help with numerical calculations, but he was not sure whether this counted as undergraduate research. The group (about 40 of us) split evenly, and some argued that whether the student understood what he was doing is completely irrelevant, and a few even maintained that if an undergraduate *did* understand it, it couldn't be genuine research. At Reed we encourage the student to be a full participant in all aspects of the research project: choosing the topic, searching the literature, designing the method of attack, performing the experiment (or doing the calculations), writing up the results, presenting a seminar on the work, and (in some cases) publishing it. If the subject is absolutely inaccessible to an undergraduate, then (in my view) it is

inappropriate for a thesis project, and a faculty member who expects to remain at the college long-term must tailor his research to accommodate undergraduate participation. If the student is simply going through the motions, with no personal ownership of the project, then he might as well be washing bottles or carrying around lead bricks—it's not research.

3.4 The Seminar Program

We maintain a regular Wednesday seminar program, which brings in speakers from all over the Northwest (and sometimes from farther afield) to speak on topics of current research interest. The seminars are very well attended (seniors are technically required to come, but we have never had to take attendance), and, with coffee and cookies provided, it is the social occasion of the week. Unlike colloquia at research universities, which are directed at the faculty and perhaps the graduate students, ours are aimed at advanced undergraduates, who participate fully and, in the spring, contribute seminars on their thesis research.

4 Conclusion

Frankly, a lot of what we do is made possible by our relatively large enrollments. Another consequence is that our students have much richer peer support than they would at many institutions, where a physics major is a lonely "nerd." From time to time there have been pressures to dumb-down our curriculum, but I think we have been wise to resist them. Serious students thrive on a real challenge, and I think one reason we attract so many is precisely *because* Physics has a reputation for being the most difficult major. Physics Education Research emphasizes the importance of active engagement on the part of the student, and I could not agree more. But I do not think this means all lectures are worthless. As an undergraduate I attended my fair share of lousy lectures, but I also attended some that were brilliant, from which I learned more in one hour than in days of poring over unintelligible textbooks or long afternoons in the laboratory. Above all I am skeptical of anyone who thinks he has found the perfect way to teach *anything*. The process of learning is just too subtle and complex for magic bullets.