Strategic Programs for Innovations in Undergraduate Physics: Project Report

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Preface

This report describes the results of the project Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP), organized by the National Task Force on Undergraduate Physics. The Task Force received support for SPIN-UP from the American Association of Physics Teachers, the American Physical Society, the American Institute of Physics, and a generous grant from the ExxonMobil Foundation. Particular thanks go to Edward F. Ahnert, President of the ExxonMobil Foundation, Truman T. Bell, program officer, and Jean Moon, consultant to the Foundation. Their assistance in shaping and focusing the goals of the project was invaluable. We gratefully acknowledge Roman Czujko and his colleagues at the American Institute of Physics Statistical Research Center for their work on the survey of all bachelor's degree-granting physics programs in the United States. Although led by the Task Force, SPIN-UP benefited from the volunteer efforts of more than 50 physicists for the site visits, the hospitality and work of the faculty of the 21 physics departments visited as part of the site visit program, and the generous time spent on the survey by 74% of the physics departments in the country. SPIN-UP is indeed a physics community effort.

Executive Summary

Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) set out to answer an intriguing question: Why, in the 1990s, did some physics departments increase the number of bachelor's degrees awarded in physics or maintain a number much higher than the national average for their type of institution? During that decade, the number of bachelor's degrees awarded in the physical sciences, engineering, and mathematics declined across the country. Yet in the midst of this decline some departments had thriving programs. What made these departments different? What lessons can be learned to help departments in the sciences, engineering, and mathematics that are—to put it generously—less than thriving? SPIN-UP, a project of the National Task Force on Undergraduate Physics, set out to answer these questions by sending site visit teams to 21 physics departments whose undergraduate programs were, by various measures, thriving. These visits took place mostly during the 2001–2002 academic year. In addition, with the aid of the American Institute of Physics Statistical Research Center, SPIN-UP developed a survey sent to all 759 departments in the United States that grant bachelor's degrees in physics. The survey yielded a 74% response rate distributed broadly across the spectrum of U.S. physics departments.

The site visit reports provided specific insight into what makes an undergraduate physics program thrive. In very compact form, these departments all have

- A widespread attitude among the faculty that the department has the primary responsibility for maintaining or improving the undergraduate program. That is, rather than complain about the lack of students, money, space, and administrative support, the department initiated reform efforts in areas that it identified as most in need of change.
- A challenging, but supportive and encouraging undergraduate program that includes a well-developed curriculum, advising and mentoring, an undergraduate research participation program, and many opportunities for informal student-faculty interactions, enhanced by a strong sense of community among the students and faculty.
- Strong and sustained leadership within the department and a clear sense of the mission of its undergraduate program.
- A strong disposition toward continuous evaluation of and experimentation with the undergraduate program.

In Chapter 4 of this report, each of these themes is further analyzed and illustrated with examples from the site visit departments. Chapter 5 provides a summary of the survey results.

Financial support for project SPIN-UP was provided by the ExxonMobil Foundation, the American Association of Physics Teachers, the American Physical Society, and the American Institute of Physics.

Chapter 1: Introduction

Undergraduate physics is the miner's canary for all undergraduate science, technology, engineering, and mathematics (STEM) programs. The number of bachelor's degrees awarded in physics in the United States began a steady decline early in the 1990s. The other STEM disciplines (with the notable exceptions of psychology and the life sciences) experienced similar declines later in the decade. The reasons behind these declines are complex. The list might include the end of the Cold War and the concomitant decline in federal defense spending, changing expectations and attitudes of students, the rise of the "dot-com" enterprises, changes in secondary-school preparation of students going on to college, and a mismatch between science faculty and student expectations. For physics, recognizing the emergence of new sub-areas, such as computational physics, biophysics, and materials physics, indicates that there is a disconnect between the standard undergraduate curriculum and how physics is currently practiced. Not only are the reasons complex, they are ultimately unverifiable. This report focuses on another issue: Amidst the general decline in the number of undergraduate physics majors, a significant number of physics departments either increased substantially the number of majors in their undergraduate programs or maintained a number of majors that kept them in the top 10% or so of departments with large numbers of majors.

What makes these "thriving" departments different from those departments that experienced substantial declines? Do they have curricula that are substantially different either in content or pedagogy from those departments that have lost majors? Do their institutions make special efforts to recruit physics majors from high schools? Do the institutions draw from a body of student applicants that happens to contain more potential science majors? Do they have special laboratory and research facilities that attract physics majors? Do they make extensive use of information technology that may be attractive to potential majors? The answer to all of these questions turns out to be—by and large—"no." What then are these thriving departments doing differently? The answer to that question is what this report is about. The evidence is drawn from site visits to 21 undergraduate physics programs that, according to criteria specified by the Task Force and described in this report, have "thriving" programs and from a survey sent to all 759 colleges and universities in the United States that offer bachelor's degrees in physics.

Caveats

Before we launch into a discussion of the survey and the site visits, several caveats are in order. First, we did not attempt to measure the physics knowledge of the students in the site visit departments. A skeptic might argue that these departments have attracted more majors by "watering down" the curriculum or by "lowering standards." We saw no evidence of this in our site visits either in the courses being taught or in the statistics provided by the departments indicating that their majors follow the general patterns of graduate school enrollment and employment seen across the country. Second, we make no claims that our site visit departments exhaust the list of "thriving" undergraduate programs in the country. In fact, we had plans to visit several additional departments but could not work out mutually agreeable schedules during the 2001–2002 academic year. Along the way, we learned of several more departments that have recently revitalized their undergraduate programs and that have evidence of success. We do believe, however, that we visited a sufficiently wide range of institutions to have evidence that what we have learned has general validity.

The third caveat is that we were, because of scheduling difficulties, unable to include thriving Historically Black Colleges and Universities (HBCUs) among the departments we visited. Several HBCUs are well known for doing an excellent job of attracting physics majors and satisfy most, if not all, of our criteria for a "thriving" undergraduate physics program. However, difficulties in arriving at mutually satisfactory schedules prevented us from adding those institutions to our site visit list beyond a "tag along" visit to Xavier University in New Orleans as part of the PhysTEC program site visits. We return to the issue of diversity in physics in Chapter 6.

Undergraduate Physics in the United States

The landscape of undergraduate physics in the United States is in some ways highly heterogeneous and in other ways relatively homogeneous. Certainly the sizes and shapes of physics departments show a broad distribution. Among the 1376 four-year colleges and universities in the United States, 759 offer bachelor's degrees in physics. Many of these have very small physics programs with only one or two faculty members. Many are of modest size with four to eight faculty members. One-hundred and seventy-three institutions offer the Ph.D. in physics. Among these institutions are some of the strongest physics research departments in the world. Some of the largest physics departments have 70 to 80 faculty members. Some physics departments include astronomy and astrophysics. In other institutions, these are separate enterprises. In some colleges, physics is part of a combined physics-chemistry department, or part of a Department of Natural Sciences. The most up-to-date statistics on physics departments are available through the American Institute of Physics Statistical Research Center (*www.aip.org*).

The commonality among physics departments lies in the physics curriculum. Most college-level introductory physics courses across the country cover a common set of standard topics, usually in a one-year course (two semesters or three quarters), including classical mechanics (roughly the first half of the course), and electricity and magnetism (roughly the second half). These courses are generally taught in the traditional lecture/lab/recitation format. A mix of "modern physics" topics, including special relativity and quantum physics, is often covered in an additional semester or quarter. The "core" upper-level courses (advanced mechanics, advanced electricity and magnetism, and quantum mechanics) are even more homogeneous with a relatively small number of standard textbooks used across the country. This homogeneity in curriculum is somewhat surprising because, unlike chemistry and engineering, the physics community has no formal certification or accrediting program for undergraduate programs. The situation in physics is more akin to that in mathematics in which the community of faculty has over the years reached an informal consensus about what constitutes the core of an undergraduate program. The undergraduate physics program, at least for those students who are considering graduate work in physics, is remarkably uniform.

To complete the portrait of undergraduate physics in the United States, we need to note some further statistics. About 50% of undergraduate physics majors go on to graduate school, about 30% in physics and 20% in other fields. At the introductory physics level, annually about 350,000 students take introductory physics across the country. This number has tracked the general college enrollment for many years. About half of these students take calculus-based physics. Among those in the calculus-based physics course from which most physics majors are recruited, only 3% take another physics course. So, by and large, introductory physics is a service course at most colleges and universities.

About 20 to 30% of students who take college-level introductory physics in the United States do so in 1,600 two-year colleges. The two-year college system provides the science education for many pre-service teachers and many minority students as well. Although this report focuses on undergraduate physics programs at bachelor's degree granting institutions, we note that the contributions of two-year colleges (TYCs) to undergraduate physics education are important. Physics in TYCs is currently (2002–2003) being studied by project SPIN-UP/TYC funded by the National Science Foundation.

At the high school level, which of course plays an important role in bringing physics to the public and in preparing the next generation of physics majors, the fraction of students taking physics has been gradually increasing over the past decade, from a level of about 20% in 1990 to almost 30% in 2002. Even more noteworthy, high school physics now has a gender balance of 50:50 men and women.

The Report

The following chapters of the report describe the recent history that led to the establishment of the National Task Force on Undergraduate Physics, the procedures used in the site visits, the analysis of the site visit reports, a brief look at the results of the nationwide survey of physics departments, and an opinion piece that attempts to draw broad conclusions from SPIN-UP. Several appendices include information on physics education resources, materials used in preparation for the site visits, lists of the site visit team members, lists of presentations and articles about SPIN-UP, the report of SPIN-UP's formative evaluator, and the short site visit "case study documents," which summarize the site visit reports.