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.

Chapter 2: History of the National Task Force on Undergraduate Physics

1995–1998

The recent history that led to the founding of the National Task Force on Undergraduate Physics and the SPIN-UP project can be traced to 1995 when Karen Johnston, then President of the American Association of Physics Teachers (AAPT), organized a strategic planning retreat for AAPT's Executive Board. Russell Hobbie of the University of Minnesota served as facilitator for the meeting. As a result of the Executive Board's discussion, the group decided that AAPT's strategy for the next few years should focus on undergraduate physics.

The physics community had begun to notice that the decline in the number of undergraduate students receiving bachelor's degrees in physics during the early 1990s was not just a statistical fluctuation. By mid-decade, the number of physics bachelor's degrees awarded dropped to a level not seen since the 1950s. The total number of college students, by comparison, had more than doubled since the 1950s. Moreover, the decline was not evenly distributed across physics departments. Collectively, Ph.D. and masters-granting institutions suffered steeper declines than did four-year colleges. And even among those categories, there were departments that had in fact increased the number of majors or maintained an already high number. Similar declines were seen in mathematics, the other physical sciences, and most fields of engineering.

The decline in the number of majors had many causes about which we will not speculate in this report. But it is important to note that the field of physics itself has changed with major efforts in biophysics, geophysics, materials science, computational science, and physics education research, most of which have no representation in the standard undergraduate physics curriculum.

At the same time, many physics departments reported that their colleagues in engineering and the life sciences were expressing dissatisfaction with introductory physics. These departments, in most institutions, send by far the largest number of students to introductory physics. As a benchmark, we had mentioned previously that less than 3% of the students who take introductory calculus-based physics, the course most likely to be taken by potential physics majors, ever take another physics course. In other words, more than 97% of the students in introductory physics courses should be viewed as "service" students.

Of course, undergraduate physics had not been totally ignored prior to 1995. Meetings of the American Association of Physics Teachers have always had a significant number of sessions devoted to undergraduate physics. Through the efforts of Project Kaleidoscope, funded by the National Science Foundation and the ExxonMobil Foundation, a number of regional workshops on undergraduate physics had been held across the country. PKAL's Faculty 21 program, designed to promote leadership among new science faculty, included a significant number of physics faculty members. With its historical ties to the Independent Colleges Office, PKAL drew its audience mostly from undergraduate institutions or institutions with small graduate programs. The major research universities collectively were not very engaged in these efforts.

On another front, the Introductory University Physics Project, funded by NSF from 1988 through 1995 and led by John Rigden (American Institute of Physics) and Donald F. Holcomb

(Cornell University), promoted the development and testing of four new calculus-based introductory physics curricula. Sixteen colleges and universities were involved in testing and assessing the new courses [Coleman, Holcomb and Rigden, 1998]. In spite of these efforts and those of many other curriculum development projects (See Appendices I and II), most undergraduate physics programs in the 1990s closely resembled those of the 1960s.

At the national level, the entire area of undergraduate science education was under review in the 1990s. In the fall of 1996, the National Science Foundation released the results of a comprehensive review of undergraduate science, mathematics, engineering, and technology (SMET) education [George, et al., 1996]. (The previous such study was done 10 years earlier.) The primary imperative of the "Shaping the Future" report is that

> "...all students [should] have access to supportive, excellent undergraduate education in SME&T, and all students [should] learn these subjects by direct experience with the methods and processes of inquiry."

"All" in this case includes not only our physics majors, but also students in service courses, including engineers, pre-medical students, and pre-service teachers. "All" also means that we need equal access to SMET education for women, minorities, and others underrepresented in the scientific community. The "Shaping the Future" report was intended to guide both the NSF and administrators in colleges and universities across the country in examining undergraduate science education programs in the years to come. This examination presented an important challenge to the physics community: Are physics programs accessible to and effective for *all* students, and do they provide students with direct experience with the methods and processes of inquiry?

Following up on the AAPT strategic planning meeting, Robert C. Hilborn, the succeeding President of AAPT, organized a September 1996 meeting of 22 physicists and three representatives from mathematics, engineering, and chemistry to consider the current state of undergraduate physics and to recommend future directions for the physics community. The report from that meeting "Physics at the Crossroads" is available through the AAPT website (*www.aapt.org*). What emerged from the discussion was a clear vision of the need for effective action for innovation and revitalization in undergraduate physics education. Undergraduate education occupies a central position in physics: it not only has the responsibility for educating the next generation of research physicists, but must be an effective part of the science education of all students, including future K–12 teachers. Hence, undergraduate education is a major responsibility, which the physics community cannot ignore.

The group urged AAPT and APS to have the May 1997 Physics Department Chairs' Meeting focus on undergraduate physics. The steering committee for the chairs' meeting, headed by Roger Kirby of the University of Nebraska–Lincoln and Jerry Gollub of Haverford College, developed a program that highlighted the issues facing undergraduate physics. The meeting, held at the American Center for Physics in College Park, MD, drew the largest attendance of any physics department chairs' meeting. The proceedings of the conference are available through the AAPT website.

Following up on the 1997 Department Chairs' Meeting, Hilborn, Ruth H. Howes (Ball State University), and James H. Stith (then at Ohio State) decided to organize a topical conference under the auspices of AAPT and APS on "Building Undergraduate Physics Programs for the 21st Century," held in October 1998 in Arlington, VA, with support from the National Science Foundation. The meeting, modeled on Project Kaleidoscope's successful workshops on undergraduate science education, asked physics departments to send teams of two or three physics faculty members for a three-day workshop. The meeting focused on undergraduate physics as a program with many components: recruiting and retaining students, providing a stimulating and challenging curriculum, engaging students in research, building a sense of community among physics faculty and students, and so on. The meeting drew 250 participants from about 100 different physics departments. (An additional 250 applicants had to be turned away for lack of meeting space.) The report from that conference is available at the AAPT website.

1999–Present

Hilborn and Howes, recognizing the strong response to the 1997 physics department chairs' meeting and the 1998 workshop, decided that a more formal organization was needed to promote attention to undergraduate physics. After considerable discussion with physics colleagues including leaders at AIP, APS, and AAPT, they proposed the establishment of the National Task Force on Undergraduate Physics (NTFUP) as a joint effort of the three physics professional organizations. The organizations agreed to contribute $5,000 each for the initial work of the Task Force. The strategic goal for the Task Force was to "revitalize" undergraduate physics in the United States. In practical terms, "revitalization" means developing creative and constructive responses to the changing environment in which undergraduate physics operates.

The Task Force was charged with four missions:

1. To provide an overview of undergraduate physics revitalization efforts and to coordinate the efforts of physics professional organizations, individual physicists and physics departments, and funding agencies.
2. To identify areas in which revitalization efforts are needed and to catalyze projects addressing those needs. Some of the projects will be national in scope; some local, some regional. Some will be centered in universities; some in professional societies. Some will require extensive external funding; some will leverage local resources. The Task Force should encourage coordination among many groups with activities in undergraduate physics.
3. To raise the visibility of undergraduate physics revitalization by having its members speak and write about the revitalization effort and maintaining communications with the entire physics community.
4. To develop contacts with undergraduate revitalization efforts in the other scientific disciplines and to promote physics as a model for undergraduate revitalization efforts.

The Task Force was to be a relatively small volunteer group of 11 physicists from a variety of institutions: two-year colleges, four-year colleges, and research universities. The members would be formally appointed by the executive officers of AAPT and APS and the Director of Resources of AIP for two-year terms with the understanding that the appointments would be normally renewed as long as the member wishes to continue to serve. The Task Force would operate as an independent group, but would report annually to the three organizations.

The Task Force membership was recruited during the fall and winter of 1999. The first appointees were

– J. D. Garcia, Professor of Physics, University of Arizona, former program officer at NSF
– Robert C. Hilborn, Chair, Amanda and Lisa Cross Professor of Physics, Amherst College, former President of AAPT
– Ruth H. Howes, Deputy Chair, George and Frances Ball Distinguished Professor of Physics and Astronomy, Ball State University, former President of AAPT
– Karen Johnston, Professor of Physics, North Carolina State University, former President of AAPT
– Kenneth S. Krane, Professor of Physics, Oregon State University, former program officer at NSF, PI of the New Physics Faculty Workshops program
– Laurie McNeil, Professor of Physics, University of North Carolina at Chapel Hill
– Jose P. Mestre, Professor of Physics, University of Massachusetts–Amherst
– Thomas L. O'Kuma, Professor of Physics, Lee College, former President of AAPT
– Douglas D. Osheroff, Professor of Physics, Stanford University
– Carl E. Wieman, Distinguished Professor of Physics, JILA, University of Colorado
– David T. Wilkinson, Professor of Physics, Princeton University

In December 2000, Karen Johnston resigned from the Task Force to pursue other professional responsibilities. She was replaced by S. James Gates, John S. Toll Professor of Physics, University of Maryland. We note, with sadness, the untimely death of David Wilkinson in September 2002.

Ex Officio members of the Task Force are

– James H. Stith, Vice President, Physics Resources, American Institute of Physics
– Jack Hehn, Director, Education Division, American Institute of Physics
– Judy Franz, Executive Officer, American Physical Society
– Fred Stein, Director of Education and Outreach Programs, American Physical Society
– Bernard V. Khoury, Executive Officer, American Association of Physics Teachers
– Warren Hein, Associate Executive Officer, American Association of Physics Teachers
– Jeanne Narum, Director, Project Kaleidoscope

In setting up the Task Force, Hilborn and Howes articulated three important principles that underlie the Task Force efforts:

1. **Revitalization is more than curricular reform.** The Task Force efforts should differ substantially from those large-scale curriculum projects supported by NSF in mathematics, chemistry, and engineering because the Task Force will focus on the entire program of an undergraduate physics department—rather than solely on curriculum and pedagogy in introductory courses. The department's program includes recruiting and mentoring students, engaging them in research, paying attention to student learning for all students, particularly those in the other sciences, those who do not intend to be science majors, and those who intend to be K–12 teachers. The program emphasizes the department's interactions with students in class, in the research lab, in advising and mentoring, and as team members in departmental efforts such as outreach to the public and to K–12 schools.

2. **The department is the critical unit for change in undergraduate education.** Individual faculty members, of course, develop the ideas and carry out the activities, but the support of a large fraction of the department is crucial if the changes are to have lasting impact. Institutional support is also important, but the action takes place at the departmental level. Consequently, the Task Force has made a major effort to include departments of all types of undergraduate institutions ranging from two-year colleges through major research universities.

2. **All reform is ultimately local.** The Task Force recognizes that "one size does not fit all" for serious educational innovation. The Task Force hopes to identify a set of principles that are common to successful physics departments, but there is a wide diversity of approaches in applying those principles to the local situation. Each department must identify its local mission and the resources needed to carry out that mission.

In December 1999 the ExxonMobil Foundation awarded the Task Force a $25,000 planning grant to support its activities during the first year of operation. The Task Force held its first meeting in January 2000 at the AAPT winter meeting in Kissimmee, FL. The Task Force meeting focused on a broad discussion of undergraduate physics and the role the Task Force might play in addressing the challenges facing undergraduate physics.

The Task Force met for a second time in July 2000 in conjunction with the Project Kaleidoscope meeting in Keystone, CO. At that meeting, NTFUP initiated several activities. The Task Force began initial plans for a program of site visits to "thriving" undergraduate physics programs. In the fall of 2000, The Task Force conducted two pilot site visits to the physics departments at North Carolina State University and the Colorado School of Mines, both of which have thriving undergraduate physics programs. In addition, members of the Task Force accompanied the site visit teams for the APS/AIP/AAPT K–12 teacher preparation project (PhysTEC) on visits to Xavier University and Oregon State University. These pilot site visits allowed the Task Force to compile a list of the characteristics of a successful undergraduate physics program and to identify the essential elements needed for change in physics departments. A protocol for the site visit teams also was developed.

The Task Force leadership then wrote a proposal to the ExxonMobil Foundation to extend the site visits to an additional 20 or so physics departments. The project also would include a survey, carried out in collaboration with the Statistical Research Center of the American Institute of Physics, of all undergraduate physics programs in the United States. In the summer of 2001, the ExxonMobil Foundation awarded $133,000 to the Task Force's project Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) to support these activities.

In addition to the SPIN-UP activities, NTFUP agreed to serve as the steering committee for the AAPT/APS/American Astronomical Society New Physics and Astronomy Faculty Workshops, supported by the National Science Foundation. This highly successful program, targeting new tenure-line faculty, has just begun its seventh year of operation with more than 95 applications received for the planned 65 participant slots. (With renewed funding, the workshop program will be expanded to accommodate about 80 participants.) The project also will provide follow-up activities at APS divisional meetings where many new faculty members present the results of their research.

The Task Force also initiated planning for a conference on the introductory calculus-based physics course to be held during the fall of 2003. Co-chairs Bob Beichner of North Carolina State University and Ramon Lopez of the University of Texas at El Paso identified a steering committee and developed plans for a conference involving teams from university departments, probably for about 250 participants. The Task Force will be heavily involved in the conference, but leadership will be drawn broadly from the physics community. AAPT has received funding for this conference from the National Science Foundation.

We have already mentioned the project Physics Teacher Education Coalition (PhysTEC), organized through APS, AAPT, and AIP with funding from the NSF and the Fund for the Improvement of Post-Secondary Education. Three of the PIs on the PhysTEC project are ex officio members of the Task Force (Fred Stein, Warren Hein, and Jack Hehn). This program is designed to aid physics departments in working with their schools of education (or equivalent programs) to improve the science education of future K–12 teachers.

Comparison with Efforts in Mathematics, Chemistry, Engineering

The Task Force focus on the departmental undergraduate program has a flavor rather distinct from the large-scale undergraduate "reform" efforts in mathematics, chemistry, and engineering. In mathematics, the calculus reform effort, begun in the late 1980s and lasting nearly a decade, focused on new ways to teach introductory calculus. The effort was supported by more than $30M in grants from the National Science Foundation. The program led to active curricular discussions and great controversy within the mathematics community. The innovations in calculus teaching have led to the publication of several widely used textbooks, and even "mainstream" calculus texts have adopted many of the features of the reform textbooks. For details, see the Mathematical Association of America report *Assessing Calculus Reform Efforts* (1995). More recently NSF has invested about $30M in the VIGRE (vertical integration of graduate research and education) in mathematics, which links undergraduate research, graduate student support, post-doctoral support and new faculty support at about 30 major research institutions.

In chemistry the focus has been on developing curricula for the college-level introductory chemistry course through the work of five large consortia. This work was begun in 1994 and as of this writing, the work on these curricula is not yet finished. Some field-testing of the various curricular components is under way. A progress report can be found in *C&EN News*, Oct. 28, 2002, pp. 35-36 (*http://pubs.acs.org/cen*). More details about the consortia can be found at the NSF Division of Undergraduate Education website:

http://www.her.hsf.gov/ehr/due/awards.cheminit.as.

In the engineering community, NSF funded seven Engineering Coalitions aimed at attracting more undergraduate students into engineering. As of this writing, the work on these projects is still under way.

The physics community's experience with IUPP and discussions with dozens of colleagues in physics and other STEM fields led Hilborn and Howes to the conclusion that the physics community was not ready for a large-scale curricular initiative analogous to the calculus reform effort. They realized that a focus on a department's total undergraduate program—courses, undergraduate research, recruiting, retaining, advising, mentoring, physics club, etc.—was crucial for making a widespread and lasting impact on undergraduate physics. Once a department developed a strategic plan and engaged a good fraction of its faculty in carrying out that plan, the department would naturally be led to look at new textbooks and new pedagogy for its courses. Hilborn and Howes realized that new courses and pedagogy were of themselves not sufficient to "revitalize" a department's program. As the analysis in Chapter 4 of this report supports, in almost all cases, the interactions between faculty and students and among students outside normal classroom times are as important as curricular developments in the thriving undergraduate programs. A collective sense of responsibility for the undergraduate program amongst the faculty is also important.

As another part of the background for project SPIN-UP, we need to mention the important efforts in physics education research (PER). PER is the physics subdiscipline that studies how students learn (or don't learn) physics and how to translate that information into effective means for teaching physics. This effort has been under way for more than 20 years, and at present some dozen or so graduate programs offer the Ph.D. in physics with a specialization in PER. PER has led to the development of new teaching materials based on this research and to an increasingly widespread awareness in the physics community of the complex of factors that influence students' learning of physics. For a review of some of the results of PER and its influence on curricular materials and pedagogy, see Chapter 4 and Appendices I and II of this report.