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.ehr.nsf.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.

Chapter 3:
Procedures for SPIN-UP Site Visits

The Task Force planned to carry out about 20 site visits to thriving physics departments during the 2001–2002 academic year. In order to facilitate a quick startup, two members of NTFUP, Ruth Howes and Ken Krane, agreed to act as project directors in exchange for release time and support for graduate and undergraduate assistants. Working closely with Bob Hilborn, the project directors hired Charles Payne of Ball State University as the external formative evaluator for the project. The team was constituted and ready to begin work in August 2001.

Site Selection

The initial step was to have the entire Task Force identify characteristics of "thriving" physics departments to be used in selecting the departments for site visits. These characteristics are

- A large number of majors (compared to the national average)
- Satisfaction of other departments within the university
- Engagement of students in the life of the department
- Undergraduate research participation
- Lively outreach efforts, recruitment programs and so on.

No single department met every criterion, but many matched several of them. In addition, the SPIN-UP leadership considered the need for diversity in type and size of institution as well as geographic distribution. Finally, letters were sent to about 100 physicists whom members of the Task Force identified as likely members of site visit teams informing them about SPIN-UP and asking if they would be willing to participate in a site visit.

The project directors developed a letter to be sent to department chairs explaining the purpose of the site visit and a letter to the site visit team, a questionnaire for the department to complete before the visit, and a protocol for the site visit. Departments were asked to pick up local expenses for the site visit and to sign a contract demonstrating their willingness to host the team. Appendix V contains the relevant letters and documents.

Site visit teams consisted of three academic physicists, who were chosen by the project directors. In so far as possible, the teams were balanced in terms of gender, ethnicity, and expertise in physics or physics education. Ideally, each team had an expert in some aspect of physics education and a faculty member active in research. In addition, each team had one member from an institution similar to the one being visited to provide perspective on administrative matters, budget, and local conditions. A member of the Task Force led each team. Generally, the team leader was identified first, and the remainder of the team was selected to balance that person's strengths. Whenever possible, teams were selected to minimize travel. This became particularly important in the immediate aftermath of Sept. 11, 2001, when air travel was difficult. The department chair and all members of the team were provided with contact information for everybody concerned.

Site Visit Information and Schedule

The site visit team and the project directors received the questionnaire report from the department at least a week before the visit. In some cases, the project directors or the leader of the site visit team contacted the department chair with additional questions. In nearly all cases, the site visit team members communicated by email or phone to discuss the upcoming visit. Each team was reminded that the site visit was not an accreditation visit, but a study of what the department was doing right.

Although individual site visit schedules varied, site visit teams usually arrived at the department in the late afternoon. The team had a dinner meeting with the department chair and/or other faculty members, particularly the director of undergraduate programs in large departments. Informal discussion at dinner allowed the department to set a tone for the visit, to discuss the schedule and to explain what the local faculty members considered important about the undergraduate program. The site visit team had the opportunity to explain SPIN-UP once again.

The next day was devoted to discussions with faculty, administrators, and students. In so far as possible, formal presentations were held to a minimum because most demographic material was already covered in the written report submitted by the department. In all cases, the team met with physics department faculty members and with physics students. Usually the team met with at least one college or university administrator. The department selected the administrator most closely associated with the undergraduate program. Frequently, the department used the site visit to publicize its undergraduate program on its own campus. We also offered any department that wanted one a colloquium by one of the team members. Large departments generally did not take advantage of this. However, it was popular among small departments, which frequently could tap funds to support the visit if it involved a public presentation. In many cases, the team met with students enrolled in service courses or with pre-service teachers. Particularly in smaller institutions, the team interviewed faculty members from other disciplines. Breakfast and lunch were generally working meals. The visit closed with a brief executive session of the site visit team followed by an exit interview with the chair, the director of the undergraduate program, or the entire physics faculty.

Following the visit, the site visit team prepared a written report for the department. Generally, the chair of the team wrote the first draft of the report, which was then re-crafted and approved by all members of the team. The report was sent to the department for correction of errors of fact and then submitted to the department chair and the Task Force. All reports are confidential. The department chair, however, could share the report at his or her discretion. The reports were generally thoughtful critiques of what made the department's undergraduate program successful. Many of them contained suggestions and comments. They followed no set format.

After receiving the written report, the project directors extracted material from the report and the department's response to the questionnaire to prepare a "case study": a formal presentation of what the department is doing and how they managed to do it, as well as steps taken to bring about change. The case study was approved for publication by the chair, who provided pictures to illustrate the online version. Twenty-one case studies appear on the AAPT website and will be included in the hard-copy version of this report. In the spirit of the site visits, the case studies highlight only the positive aspects of the department's undergraduate programs.

All members of the site visit team and the department chair were asked to fill out an open-ended evaluation of the site visit. The departments universally perceived the visit as a positive experience. Many of them stated that the most useful aspect was the time the department spent thinking about its own undergraduate program. Site visitors generally enjoyed seeing what was happening in another department and felt that the visit had been a useful experience for them. The size of the teams was considered appropriate, but in some cases, the visits seemed too short. This was particularly true in large departments. In general, the major critique of the scheduling was not having enough time to talk with students. Site visitors also emphasized the difference between SPIN-UP site visits and the usual accreditation visits.

That SPIN-UP could complete 21 site visits within one academic year represents a remarkable commitment to undergraduate education by a large segment of the physics community: the 21 site visit departments and over 70 faculty members who made up the site visit teams. SPIN-UP funds covered travel expenses for the site visit team members. The host departments paid all local housing and meal costs. Including accommodation expenses provided by the host departments, the volunteer time of the site visit teams and the time spent preparing the reports, we estimate that actual and in-kind contributions for the SPIN-UP project from the physics community are more than $130,000 beyond the funding received from the ExxonMobil Foundation.

List of Site Visits

1. Angelo State University, San Angelo, TX, *Feb. 7–8, 2002*
2. University of Arizona, Tucson, AZ, *Jan. 28–29, 2002*
3. Bethel College, St. Paul, MN, *May 2–3, 2002*
4. Brigham Young University, Provo, UT, *Nov. 15–16, 2001*
5. Bryn Mawr College, Bryn Mawr, PA, *April 15–16, 2002*
6. Cal Poly State University, San Luis Obispo, CA, *March 7–8, 2002*
7. Carleton College, Northfield, MN, *May 12–13, 2002*
8. Colorado School of Mines, Golden, CO, *Oct. 5–6, 2000*
9. SUNY Geneseo, Geneseo, NY, *April 25–26, 2002*
10. Grove City College, Grove City, PA, *Oct. 25–26, 2001*
11. Harvard University, Cambridge, MA, *Dec. 9–10, 2001*
12. University of Illinois, Urbana-Champaign, IL, *Nov. 12–13, 2001*
13. University of Wisconsin–La Crosse, WI, *March 6–7, 2002*
14. Lawrence University, Appleton, WI, *April 17–18, 2002*
15. North Carolina State University, Raleigh, NC, *Oct. 9–10, 2000*
16. North Park University, Chicago, IL, *Nov. 29–30, 2001*
17. Oregon State University, Corvallis, OR, *May 19–20, 2002*
18. Reed College, Portland, OR, *Feb. 20–21, 2002*
19. Rutgers University, Piscataway, NJ, *Dec. 3 –4, 2001*
20. University of Virginia, Charlottesville, VA, *Feb. 28–March 1, 2002*
21. Whitman College, Walla Walla, WA, *April 25–26, 2002*

Chapter 4:
Analysis

This section contains the analysis of the site visit reports. Here we extract the features that we believe distinguish a thriving undergraduate physics program from one whose performance is less than stellar. For each of the conclusions, we back up our statements with evidence from the site visit reports. The examples were chosen from the site visit reports to give some sense of the breadth of activity in the departments we visited. The examples used are not intended to endorse a particular activity as the "best practice" for a particular feature. As we mentioned previously, almost all of the site visit departments were exemplary in almost all of the features we describe. We need to emphasize, however, that it is difficult to establish a precise cause-and-effect relationship for any of the features taken individually. The collective effect, on the other hand, is striking.

General Comments

Before going into the details of the analysis, we make several important general comments:

1. There is no evidence for a single "magic bullet"—one action or activity or curricular change—that will make an undergraduate physics program thrive. In fact, it is the interaction of many activities that seems to be the key feature. Most struggling departments have some of the features identified in the thriving departments, but the interactions and the focus on undergraduate physics are lacking.
2. It has taken several years for departments that were not thriving to initiate changes and to build a thriving program. Changes take time to settle in and to make an impact.
3. Most of the crucial features do not require major external funding. The critical resource is personnel—dedicated and energetic and persevering—with a vision for a thriving undergraduate physics program. This vision is understood and clearly articulated, not only within the department, but in the institution's administration. Nevertheless, we don't wish to downplay the importance of resources: The department must have at least modest resources, both financial and human, that will allow for experimentation with the curriculum and support for student research, a physics club, and so on.
4. It is important to emphasize that none of the thriving departments have "watered down" their undergraduate programs to attract and retain majors. The site visit teams made no attempt to measure student learning directly. The teams did look at indirect evidence of what students have learned: (a) the quality and sophistication of student research projects, (b) employment of graduates, and (c) admission to graduate programs in physics or closely related fields By these indirect measures, the site visit departments seem to have rigorous curricula that prepare their students well for a variety of careers. Some of the thriving departments seem to recruit many majors from would-be engineers, mathematicians, or computer scientists just because the physics program is viewed as intellectually challenging. The key element is the sense of community that the faculty and students have established. The faculty and students work together to see that

the students benefit from the challenging curriculum.

4. Although we believe that the 21 site visit departments indeed have thriving undergraduate programs, we do not claim that these are the only such departments. Our search for thriving departments turned up at least another dozen or two departments that we would have been delighted to visit if we had had the time and resources. Furthermore, we do not claim that these site visit departments are "perfect" or "ideal" departments. Nor would the departments make such claims. They all recognize that there remains room for improvement even in the most successful programs. In addition, as we emphasize in several places in this report, what works for one institution may not be appropriate for another.

As we read through the site visit reports, we quickly realized that a relatively short list of common elements characterized the thriving departments. These elements can be expressed in several ways. First in broad categories, we recognized:

- A supportive, encouraging, and challenging environment for both faculty and students characterized by professional and personal interactions among faculty and students and among students both in class and outside class. The students expressed a strong sense of belonging to the professional physics community.
- Energetic and sustained departmental leadership focused on a vision of an excellent undergraduate physics program with continuing support from the institution's administration.
- A sense of constant experimentation with and evaluation of the undergraduate physics program to improve physics teaching, undergraduate research, student recruitment and advising and other interactions with students in line with the local needs and mission of the department and the institution.

An Analytic Outline

We also analyzed the reports with more specific categories. Here we give an outline of those categories. The remainder of this chapter expands this outline with examples from the site visit departments.

Leadership

1. Sustained leadership with a focus on undergraduate physics within the department. Most faculty members in the department placed a high value on undergraduate education.
2. A clearly articulated undergraduate mission and a vision of how that mission supports the mission of the institution. The vision is shared among the faculty and communicated to the students.
3. A large fraction of the departmental faculty actively engaged in the undergraduate program.
4. Administrative support from the dean/provost for the department's undergraduate efforts.

Supportive, Encouraging and Challenging Environment

1. Recruitment program either with high school students or with first-year students at the institution.
2. A strong academic advising program for physics majors that actively reaches out to the students.
3. Career mentoring: an active effort to make students (particularly beginning students) aware of the wide range of careers possible with a physics degree. For upper-level students the mentoring includes advice on how to apply for jobs, graduate schools, etc.
4. Flexible majors' program: Several options or tracks leading to the bachelor's degree are available (and promoted).
5. 3/2 dual-degree engineering programs, particularly at four-year colleges without engineering departments.
6. Mentoring of new faculty, particularly for teaching.
7. Active physics club or Society of Physics Students chapter.
8. Student commons room or lounge.
9. Opportunities for informal student/faculty interactions.
10. Alumni relations. The department keeps in contact with alumni, keeps data on careers of alumni, and so on.

Experimentation and Evaluation

1. Special attention paid to the introductory physics courses. The "best" teachers among the faculty are assigned to those courses.
2. Undergraduate research either during the summer or during the academic year.
3. Physics education research and external funding. Most of the faculty are aware of the findings of physics education research and pedagogical innovations based on physics education research. Some departments had one or two faculty actively engaged in physics education research. Some faculty members have received external funding for education projects.

In the following sections we will describe these categories in more detail, providing evidence for the importance of each of these activities.

The Elements of a Thriving Undergraduate Physics Program

Departmental Leadership

It should come as no surprise that departmental leadership is important. In most colleges and universities, faculty members work as fairly independent entrepreneurs, teaching their courses alone and developing their own research programs. They are evaluated and promoted based on their individual teaching and research efforts. There is no direct incentive from the institution or from the profession for working collectively on undergraduate physics. Even in four-year colleges (without graduate programs), there may be little collective responsibility for the undergraduate program. When the number of majors drops or the pre-med students complain about their experiences in an introductory physics course, it is easy to blame the students (who are obviously not as dedicated as we were when we were students, and certainly not as well-prepared), the admissions office (which always ignores students who are interested in science), or the economy, or lack of support from the administration. In thriving physics departments, however, there is a strong sense that the department collectively has the responsibility for shaping a thriving undergraduate physics program for the students that the institution brings to campus (not the students the department wishes it had). Often the chair or a group of faculty has taken the lead in helping the department maintain a focus on improving the undergraduate program. In larger research departments, it is often the chair for undergraduate studies. Furthermore, there is a tradition of keeping that focus even when the leadership changes hands.

It is important to note that in all the thriving departments, faculty members agreed that the undergraduate program was everyone's responsibility. Although almost all of the thriving programs had identifiable leaders, none of the thriving undergraduate programs was sustained by a "hero" operating in relative isolation.

◗ **Sustained leadership over the years:** The physics department at SUNY Geneseo was founded by Robert Sells (of Weidner and Sells textbook fame). From the beginning, the department enjoyed a focus on establishing and maintaining an energetic undergraduate physics program. The succeeding chairs have worked hard to maintain that focus and have helped Geneseo establish itself as one of the premier undergraduate programs in the SUNY system.

◗ **Leadership that revived a dying department:** The physics department at the University of Wisconsin–LaCrosse faced almost certain extinction in the late 1980s. The dean recommended and supported the hiring of a new chair from outside the university. The new chair, with support from the administration, increased and improved staffing and research activity, and restructured the curriculum. The new chair took the lead in convincing others in the department that they could have a thriving physics program. After two years of negotiations, efforts aimed at recruitment, undergraduate research, and 3/2 dual-degree programs were put in place. Subsequently, the number of physics majors increased dramatically.

◗ At the **University of Arizona,** the physics department head, with support from the higher administration, refocused the department's energies on its undergraduate program. The department now graduates about 22 physics majors and six engineering physics majors each year. About 25% of the undergraduate physics degrees are awarded to women, a figure above the national average.

We should emphasize that good leadership is not dictatorial. The leader(s) engages the entire department (or a good fraction of the department) in developing and sustaining the undergraduate program. The leadership is exercised more often by talking, persuading, cajoling, and more talking than by laying down fiats. And perseverance is primary. As we have mentioned many times, it often takes several years for the results of changes in the undergraduate program to make themselves felt. Effective leaders are patient and persevering, and they keep the department's eyes focused on the target over long periods of time.

Mission and Vision

A crucial part of departmental leadership is articulating the mission of the department, developing a vision of where the department needs to go, and keeping the department focused on that mission. It is too easy to say that the mission of the department is to "teach physics." The crucial notion is seeing how that mission is articulated for each individual department. What are the interests and needs of your students? What are the capabilities of your faculty and your institution? A small liberal arts college is not going to have either the numbers of faculty or the resources of a large research university. The small-college students are likely to have different career aspirations as well. A department in a school with a large engineering program is likely to have a mission different from that of a department that has a large pre-service teacher audience. Of course, a department's mission may change. For example, a department that in the past was mostly a service department for other science majors may decide to enhance its program for physics majors.

Each of the thriving departments we visited had a clear sense of its mission, and the departmental leadership helped articulate that mission. This articulation was particularly important for smaller departments as they recruited new faculty members. It is important that new hires understand the department's mission and that they are able and willing to support that mission.

◗**Brigham Young University** maintains a modest graduate program in physics with about 25 graduate students. However, the department has made a strong commitment to undergraduate physics with an emphasis on undergraduate research because the university has 32,000 students of whom 30,000 are undergraduates. About 98% of BYU's students are members of The Church of Jesus Christ of Latter-Day Saints.

◗The **Reed College** Physics Department emphasizes undergraduate research and independent work that supports Reed's overall emphasis on close faculty-student research collaborations. Four of Reed's physics majors have been recognized for their research work by the APS Apker Award (one winner, three finalists). All Reed students do a senior thesis project. External funding in the department has exceeded $2 million over the last decade.

Substantial Majority of Engaged Faculty

We all know of situations where a lone, energetic, and hard-working colleague initiated innovations in a course. Students seemed to enjoy and benefit from the change. But when the faculty member rotates out of the course or goes on sabbatical leave, the innovations are dropped. All of our site visits convinced us that having a large fraction of a department's faculty engaged in the undergraduate program is crucial to developing, and perhaps more importantly, to sustaining innovations that keep a program thriving. We emphatically point out that most of the departments displayed a broad spectrum in the level of engagement, and individual faculty members' engagement varied significantly over the years. There were periods of intense work, for example while revising large-enrollment introductory courses, with periods of less intense engagement while others carried the banner. But in all cases, the department as a whole took responsibility for the undergraduate program. Those faculty members who were less engaged nevertheless provided strong support for those who were, for the time being, carrying a somewhat heavier load. Most members of the department took part in discussions of what changes should occur and most took part in figuring out what was working and what needed repair.

Admittedly, the issue of engagement plays out differently for solely undergraduate institutions, in which perforce all faculty are engaged only in the undergraduate program, and research universities, in which—by necessity—substantial attention must be paid to the graduate programs, post-docs, and research that most likely does not involve undergraduates. Nevertheless, in solely undergraduate institutions, it is easy to find examples of physics departments in which there is little collective effort toward keeping the physics program thriving. Each faculty member may do a fine job teaching and doing research, but there may be little or no collective effort to keep the overall program alive and thriving.

How is this engagement sustained, particularly in light of pressure on the individual faculty member to spend more time on research, institution-wide committee work, professional society activities, not to mention home and family? Although the precise answer is difficult to provide, it seems that in the departments with thriving undergraduate programs, this sense of collective responsibility has been carefully cultivated over the years by the departmental leadership. New members of the faculty are mentored and guided to adopt this same philosophy. The faculty members of those departments meet often, and the undergraduate program is discussed routinely. We don't want to underestimate the difficulties faced by faculty in research universities. Their promotion and tenure decisions depend most heavily (if not exclusively) on their research productivity, despite increasing emphasis on teaching. The emphasis on research occurs at both the departmental and institutional levels and is re-enforced by the physics community, where the public recognition for research accomplishments overwhelms recognition for contributions to physics education. We are optimistic, however, that many research departments are beginning to recognize the importance of undergraduate education, if only to keep up the supply of future graduate students in physics. Many, in fact, are paying more attention to the broader role of physics in undergraduate STEM education.

This increased attention in physics shows up in the regular nationwide department chairs meetings that have a major focus on undergraduate physics. Some of these meetings, as mentioned in Chapter 2, are held by the physics professional organizations. The chairs themselves organize others, notably the "Mid-west Physics Chairs Meeting" and a meeting of chairs from departments with highly ranked graduate programs.

◗ At **Harvard,** the entire physics department meets to discuss issues of the undergraduate program. Curricular issues are hotly debated. Over the years, all of the faculty members teach in the undergraduate program. As one faculty member expressed it: "The faculty work hard to make the Harvard undergraduate physics program the best in the country."

◗ Six years ago the Department of Physics at the **University of Illinois** began a major revision of the calculus-based introductory physics sequence taken by physics majors and engineers. A team of eight faculty members worked on this revision over a period of several years (with some 10 faculty-semesters of released time to help the effort), building a solid infrastructure for a series of courses that faculty now enjoy teaching. At present, nearly 75% of the department's faculty members have taught in the revised course sequence.

◗ At the **University of Virginia,** about two-thirds of the physics department faculty are involved in teaching undergraduates at any one time. Most of the faculty see teaching as a significant part of their professional responsibility. The department has an undergraduate committee of five faculty members who make recommendations on changes to the curriculum and on other matters that affect the undergraduate program. A teaching committee reviews the teaching performance of all faculty members and plays an important role in the evaluation of faculty members.

Administrative Support

Having good administrative support would seem to be an obvious and easy matter. What administrator would not support the efforts of the faculty to improve an undergraduate program? Real-life administration, on the other hand, is heavily weighted with institutional history and institutional constraints. If a physics department has been producing only one or two bachelor's degrees per year for decades and the biologists and engineers are always complaining that introductory physics provides a very high and rough hurdle for their students, one can understand why the dean may be reluctant to provide more resources for what she thinks is a lost cause. Furthermore, the physics department is probably not the only department that needs serious attention. On the other hand, most deans are quite willing to support departments that have taken the initiative themselves, made some modest changes and have had some modest success. In all of the visited institutions with thriving undergraduate physics programs, we found strong administrative support for the physics department. In fact, in many cases the physics department was the dean's paradigm for curricular innovation, support of students, and good citizenship within the institution. It is not surprising that those deans were willing to provided additional faculty and financial resources for the department when the department made a convincing case for those resources. This support is a direct consequence of having the department's mission and vision aligned with that of the institution.

◗ The administration at **Lawrence University** provided the physics department with about $600,000 over the past 10 years to supplement external funding of about $2.5M from Research Corporation, the Keck Foundation, NSF, the Sloan Foundation and several other funding agencies. A significant fraction of this money has been used to develop "signature programs" in laser physics and computational physics, specialty programs that provide uniqueness and drawing power to the department's overall offerings.

◗ At **Grove City College,** the Dean and Provost reported that the physics department's dedication to good teaching in its service courses has been a major contributor to the "rise of physics" on the Grove City campus. Two faculty positions have been added to the physics department in the last nine years (making a total of five full-time faculty) to support the increasing number of physics majors and the increasing role of physics in teaching service courses to nonmajors.

Supportive, Encouraging and Challenging Environment and Recruitment

Almost all of the thriving physics departments had some form of active recruiting program. They had all realized that having a vibrant and exciting undergraduate physics program was necessary but not sufficient to bring students into the program. The students had to find out about the program; they had to have a sense that physics was a good undergraduate major to pursue, and that they would find the program accessible but challenging. Given the lack of information among high school students about what careers are supported by a background in physics, combined with a lack of experience with physics in high school (about 30% of high school students take physics), it is not surprising that physics departments need to do some recruiting. We found a wide spectrum of recruitment activities. Some departments were quite successful working directly with high school students and high school physics teachers. Some departments visited high schools; others invited the students for a Science Day on campus. Others found programs with high school students less productive.

Many departments actively recruited in their introductory physics courses by including career information, providing contacts with upper-level physics majors, and talking personally with students who showed an aptitude for physics. Some sponsored informal "get to know the department" meetings with short talks about research in the department, particularly student research, and career paths of recent alumni, all enhanced by vast quantities of pizza. Some invited potential majors to departmental picnics or softball games. Many chairs wrote letters and sent departmental brochures to all admitted students who indicated some interest in physics or whose academic records indicated that they might be potential physics majors.

Several of the site visit departments offer a one-credit-hour course ("Introduction to Physics as a Profession," for example) for first-year students aimed specifically at introducing the students to the department and to the potential careers one can pursue as a physics major. These short courses were often cited by students as being very influential in their decisions to become physics majors.

◗ The **Lawrence University** physics department invites roughly 30 "select" high school students to visit campus for a weekend workshop in February or March. Each of the students is hosted by a physics major from Lawrence and spends time doing laboratory work using research equipment at Lawrence. Approximately 30% of the workshop attendees matriculate at Lawrence. The annual cost of $15,000 is underwritten by the Office of Admissions, which handles the mailings and invitations. This recruiting effort has had a profound effect on the development of physics at Lawrence.

◗ At **North Park University**, the chair of the Physics Department has the Admissions Office send names of all prospective students interested in physics, engineering, or science to the department. The chair phones or emails all of these students and invites each prospective student and their parents personally to visit the department and follows up the visits with a personal and often humorous postcard.

◗ At **Bryn Mawr College**, students involved in the introductory physics courses are given tours of the research laboratories. Upper-level students involved in the research laboratories give presentations for these students at a mini-symposium. Many students cited the research opportunities as playing an important role in their decisions to become physics majors.

Advising

Once students declared themselves as physics majors, the thriving departments provided active advising. The advising took many forms: In some departments, one faculty member served as undergraduate advisor for all the majors, providing common information and advice, resolving scheduling problems, and checking on required courses, for example. In other departments, the advisees were spread among all the faculty. Some departments used a mixed mode with one faculty member serving as chief advisor but with all students assigned to other faculty members for additional advice. No one scheme seemed to work significantly better than the others.

In additional to formal advising, the students in the thriving programs reported to the site visit teams that faculty were available almost 24/7 for informal advising, help with homework (even for courses they were not teaching), career information, and just general talking about life. We got the sense that many of these informal discussions often dealt with course selection, how to get a summer research position, and other topics that might normally be relegated to formal advising appointments.

◗The Undergraduate Program Director in the Department of Physics and Astronomy at **Rutgers University** handles all of the advising for undergraduate majors. The faculty and the departmental leaders believe that centralizing the undergraduate advising was the most important factor leading to the growth in the number of physics graduates (doubling from about 20 in 1980 to 40 in 2000). The students support this conclusion, expressing strong appreciation for the director's individual concern for them and for the consistency of the advice they received.

◗At **North Carolina State University,** students declare their majors when entering the institution. The physics majors enter a special section of the introductory course with special laboratories and a unique curriculum. A small group of advisors works closely with the physics majors and follows them from freshman year forward.

Career Mentoring

Today's students have a strong interest in shaping their careers relatively early in their undergraduate years. One might argue that students have always had strong career interests, but today's students seem to be particularly vocal and focused on careers. If the students are not, certainly their parents are. Physics finds itself in an unusual situation in the sciences: Most students (and their parents) think that the only careers available to physicists are those in academe or in basic research in the national labs. In fact, less than 20% of people with a degree in physics (bachelor's, master's, or Ph.D.) pursue careers in academe or the national labs: About 30% of physics bachelors go on to graduate school in physics. Of those, less than 40% end up with Ph.D. jobs in academe or national labs. (See the AIP Statistical Research Center website for further details.) The vast majority do something else. To complicate matters, most high school physics teachers and physics faculty members in colleges and universities are only dimly aware of these (obviously misnamed) "alternative" career paths. For better or worse, most of these other jobs do not have "physicist" in the job title. Almost all of the site visit departments provide extensive career information and career counseling to their majors and potential majors. One of the most effective career advising tools is pointing to the department's own alumni. Many departments have their alumni return to give talks about their careers in industry and business as well as those who pursue academic and basic research careers.

As an aside, we note that the physics professional organizations AIP, APS, and AAPT now have available extensive information about careers pursued by people with physics degrees. Students can be directed to these organizations' websites for abundant and up-to-date career information. APS's Committee on Career and Professional Development runs a CPD liaison program in which a faculty member in a department is designated as the primary point person for APS career information.

◗ At **Carleton College,** prospective physics majors take a one-credit-hour course "What Physicists Do" that brings to campus alumni as well as other speakers to show how a major in physics leads to a wide range of careers.

◗ The **University of Arizona** physics department hosts an Academic Support Office for undergraduates. Among other functions, the office maintains an employment database where students can find information on internships as well as permanent employment. The department also maintains a webpage listing of alumni and their present activities, and a program under which alumni are invited back to give talks to the department.

◗ **Bethel College** maintains close ties with high-tech industries in the Minneapolis/St. Paul area and places many students in internships with these industries. (These connections often lead to equipment donations and funded research contracts, as well.) The entire physics faculty at Bethel meets to match students with available internships.

Introductory Physics Courses

For most physics departments, the large introductory physics courses are a key component in their undergraduate programs. This is where the department has its first contact with potential majors and where it provides its largest service to the rest of the institution. The economics of higher education often dictates that these courses have large sections and only a few faculty members (and often just one) assigned to teach them. All of the site visit departments work very hard at making the introductory courses as good as possible. Most assign only their "best" and experienced faculty to those courses. When new faculty members rotate into those courses, they often do so first as "apprentices" with more experienced faculty. Many faculty teaching in those courses are using innovative pedagogy such as peer instruction [Mazur, 1997], just-in-time teaching [Novak, et al., 1999], and active demonstrations [Sokoloff and Thornton, 1997] [Thornton and Sokoloff, 1998]. Few of the departments, however, would claim that they are doing anything radically different with their introductory courses. Some departments have developed special courses or special sections of the introductory course to appeal to potential physics majors.

The common feature among the site visit departments was a sense of constant monitoring and refinement of the introductory courses, both those for majors and those for nonmajors. By and large, most of the departments had a sense of collective "ownership" of the introductory courses. Although individual faculty members would tinker and adjust the introductory course when they were teaching it, no major changes were introduced without significant discussion and buy-in from the rest of the department.

◗The Physics Department at the **University of Illinois** undertook a multi-year, massive restructuring of its introductory physics courses, which serve a very large number of engineering majors. The goal was to develop a solid infrastructure so that teaching the courses did not require superhuman efforts. Students attend lectures twice a week, submit homework on the computer, and then attend a two-hour discussion section covering the same material. The labs were reorganized to emphasize conceptual understanding based on the "predict, observe, explain" model of Thornton and Sokoloff [Thornton and Sokoloff, 1998]. Lectures are based on PowerPoint presentations so all lecturers cover the same material. T.A. training has been enhanced to prepare the T.A.s for the new type of discussion sections. In 2001, 75% of the T.A.s were rated as excellent, up from 20% in 1997. The department also added two new positions. One is a staff position to assist with the introductory courses. The other is a new administrative position–"Associate Head for Undergraduate Programs."

◗At **Brigham Young University**, the physics department supports all the introductory courses with tutorial labs, peer student assistants, and faculty assistance with special rooms available and staffed for the introductory physical science courses and the introductory physics courses. The department maintains faculty committees to oversee the service courses and interact with appropriate departments on campus for which these courses provide support.

◗ **Carleton College** offers an unusual structure for its introductory physics course. Its one-term (10-week)-duration course is split into two half-term courses. Starting in the Winter Term, students usually take a one-half-term course in Newtonian Mechanics or, for students with sufficient high school preparation, a half-term course on "Gravitation and the Cosmos." Both sections are followed by a half-term on Relativity and Particles. The notion is to expose the students to exciting, up-to-date topics early in their careers. Other traditional introductory topics are subsumed into an intermediate-level sophomore sequence of atomic and nuclear physics, two half-term courses in classical mechanics and computational mechanics, and electricity and magnetism.

◗ At the **University of Virginia** about one-half of all undergraduates students have taken at least one course in the physics department. Many non-science majors take one or two semesters of "How Things Work" or "Galileo and Einstein" or a conceptual physics survey course. The physics department has an excellent reputation among non-science students at Virginia.

Flexible Majors' Program

Most of the site visit departments have developed a set of requirements for the major with considerable flexibility to meet the needs of students with a broad spectrum of career interests. Many programs have a set of core requirements that all majors satisfy, but they leave considerable flexibility for options at the upper level. This flexibility seems to be appearing in many physics departments across the country. Many site visit departments had explicit "tracks" for students who want to combine physics and engineering, physics and chemistry, physics and computer science, physics and biology, even physics and business. Others allow for a concentration within physics, for example lasers and optics or materials science. This flexibility is often important to students who may want additional specialization beyond the usual array of undergraduate physics courses to enhance their career options or to follow up on some scientific or technical interest beyond physics. This flexibility also reflects the current practice of physics, where some of the most exciting developments are occurring at the interfaces between physics and other scientific disciplines.

These departments have dealt with the unavoidable criticism of "diluting the major" or "making the major less rigorous" by recognizing that students who intend to go to graduate school in physics, for example, need to have taken a set of courses somewhat different from those taken by a student who intends to go to medical school. As another example, a student who intends to be a high school physics teacher is probably better served by taking some biology and chemistry courses rather than a second advanced course in quantum mechanics. The advising program plays a critical role in guiding the students in choosing the set of courses that best meets their needs.

It is important that the department treat students who don't intend to go to graduate school in physics as full citizens of the department. It is too easy to fall into the trap of saying that only people with Ph.D.s in physics are the ones who may be called "physicists." The site visit departments seemed universally to go out of their way to celebrate the diverse career paths of their students.

◗ **Harvard University's** physics department, which graduates 50 to 60 majors each year, supports two levels of majors: The basic program requires a total of 12 courses in physics and mathematics. The "honors" program requires in addition two advanced mathematics courses, an advanced lab course, and three additional physics courses. There are also several joint-major programs: physics and chemistry, physics-mathematics, physics-astronomy, physics-history of science, a biophysics option, and a physics teaching program for those intending to teach physics at the secondary school level.

◗ **Whitman College,** which graduates about 10 majors each year, has several "combined majors" programs in mathematics-physics, astronomy-physics, and geology-physics.

◗ **Oregon State** radically revised its upper-level curriculum to allow more flexibility for its many transfer students and to provide a more integrated experience for its majors. The junior year consists of nine 3-week "paradigms" on such topics as Oscillations, Vector Fields, Energy and Entropy, Waves in One Dimension, and so on. In the senior year the students take a series of more traditional capstone courses in classical mechanics, quantum mechanics, electricity and magnetism, statistical mechanics, optics, and mathematical methods. The development of the Paradigms model was supported by grants from the National Science Foundation.

◗ The physics department at **Rutgers University** offers four different options for undergraduate physics majors. The Professional Option is aimed at students who intend to go to graduate school in physics. The Applied Option and the Dual-Degree option attract students looking for more applied work in physics or engineering. The General Option is intended for students who plan careers in law, medicine, or secondary-school teaching. A new astrophysics major has recently been introduced. The department is considering adding an engineering physics degree.

3/2 Dual-Degree Engineering Programs

Many colleges without their own engineering schools are participants in 3/2 dual-degree engineering programs in which a student spends three years at the college and two years at the cooperating engineering school. The student then graduates with a B.A. from the college and a B.S. from the engineering school. In many cases, these students are physics majors. Physics departments have found that a 3/2 engineering program is quite attractive to high school students who are interested in engineering careers but who want a liberal arts background before committing themselves to a more technical career. The students may also want to have a few years to think about which flavor of engineering they want to pursue. No matter what the specific motivation, many colleges and universities without engineering programs find that a 3/2 program attracts students who would not otherwise consider their programs. Once the students are enrolled, a significant number decide to stay four years at the college and be "regular" physics majors, partly because they want to graduate with their friends and particularly because they find the physics department hospitable. Many of these students then go to graduate school in engineering or applied physics.

◗ **SUNY Geneseo** admits about 40 students each year interested in the 3/2 dual-degree engineering program. Many of these students are subsequently recruited to be physics majors, and many of them decide to finish a physics major program at Geneseo in four years and to pursue graduate studies in engineering.

◗ **Bethel College** offers both 3/2 and 4:2 (B.S. in physics, M.S. in engineering) programs and has recently instituted a major in Applied Physics.

◗ The **University of Wisconsin-LaCrosse** recently established 3/2 arrangements with the University of Wisconsin campuses in Madison, Milwaukee, and Platteville and with the University of Minnesota. About half of the graduating majors each year are in the 3/2 program.

Undergraduate Research

It is safe to say that the past 20 years have seen a revolution in undergraduate research participation. Fairly rare several decades ago, undergraduate research is found nowadays in almost all colleges and universities. These institutions and their students have recognized that participating in research where the answers cannot be found in the back of the book and where even the procedures are not initially well-defined is a powerful educational tool. It gives students a sense of what actual scientific research is like and it motivates students because they see their classroom learning in action. In addition, having students engaged in the research helps move along the faculty members' research programs, particularly at colleges without graduate programs. Most undergraduate research programs provide opportunities for the students to give public presentations of their research results. These presentations are excellent opportunities to develop the students' communication skills, important for almost all careers, and makes the students feel that they are indeed part of the scientific research community.

The 1998 Boyer report (*http://naples.cc.sunysb.edu/Pres/boyer.nsf/*) called upon research universities to achieve a greater integration of research with undergraduate education and made specific suggestions for curricular reform to achieve that end. A 2002 follow-up report (*http://www.sunysb.edu/pres/0210066-Boyer%20Report%20Final.pdf)* indicated the considerable progress that has been made in achieving the goals outlined in the earlier report. Both of these reports are available through the SUNY–Stony Brook Reinvention Center (*http://www.sunysb.edu/Reinventioncenter/*). Although these reports dealt only with research universities, they contain important lessons for undergraduate programs at all types of institutions.

All of the site visit departments had thriving undergraduate research programs. About half of them *require* participation in undergraduate research for the major. In addition to on-campus research with their own faculty, many students take advantage of off-campus opportunities, for example, in the Research Experiences for Undergraduate programs sponsored by the National Science Foundation and some of the national laboratories. In many departments, students are encouraged to participate in research even after their first and second years, just to see what research is like and to experience working on a research team. Most undergraduate research programs focus on work in the summer after the junior year and during the senior year, often culminating in a significant research thesis or report.

Undergraduate research participation benefits both the students and the department in many ways that go beyond just the completion of the research. Students gain experience working in teams and communicating their results, both orally and in written reports. The shared research experience gives the students a deserved sense of being part of the scientific community, not just passive consumers of science through their courses. Most departments recognize the importance of undergraduate research in building a sense of community within the department. In addition, the time students spend working directly with faculty members on research provides many opportunities for informal advising.

◗ **Angelo State University** physics majors are required to complete a three-hour research course prior to the fall semester of the senior year and to participate in a student research project either during the academic year or during the summer.

◗ At **Brigham Young University** two-thirds of the 28 physics faculty members are engaged with undergraduate students doing research. (The department also has a Ph.D. program with about 25 graduate students.) One faculty member serves as undergraduate research coordinator. A senior thesis, honors thesis, or capstone project is required for the Bachelor of Science degree in physics. With 45 to 49 graduates per year, the research supervision load of the faculty is fairly high. The university provides about $20k per semester to support the research of 20 to 25 students. The department also hosts an NSF-funded Research Experience for Undergraduates program during the summer. More than half of the department's B.S. in Physics and Physics and Astronomy majors gave talks at regional or national meetings last year.

◗ **Carleton College** physics majors complete a senior thesis project, which may be in an area associated with faculty research. Other thesis topics evolve out of a recently improved junior-year laboratory course (entangled photon detection and atom trapping, for example). Others focus on contemporary research topics such as LIGO or CP violation.

Physics Clubs and Commons Rooms

Almost all of the site visit departments have an active physics club or Society of Physics Students chapter. The activities of these clubs varied from college to college but they included organizing informal gatherings of students and faculty, running outreach programs to the local schools, organizing tutors for introductory physics students, inviting and hosting speakers for the physics colloquium series, talking with first-year students about becoming physics majors, providing feedback to the department about the undergraduate program, and so on. Most of the clubs have a faculty advisor, whose role is often limited to seeing that the club's activities get started each year with the students, in practice, doing almost all of the work. The benefits of having an active physics club include giving a structure for building a sense of community and responsibility among the students, inviting new students into that community, and providing many opportunities for informal interactions among the faculty and students. The students in those departments with SPS chapters enjoyed the contact with the American Institute of Physics and the regional "zone" meetings of SPS chapters from neighboring institutions. AIP provides a newsletter and career information to students in SPS chapters.

Almost all of the site visit departments provide some commons space for their majors. Sometimes the space is just the back of a classroom or a lab room that was vacant in the evenings. In most cases, the students have access to a dedicated room equipped with a computer or two, some physics reference books, and, of course, a coffee pot and microwave oven. Providing the student space signals to the students that the department takes them seriously and that they are indeed part of the department. The study sessions and physics club meetings held in that space contribute to the sense of community among the students.

◗ The SPS chapter at the **University of Arizona** is involved in a number of aspects of the Department of Physics programs, such as interviewing prospective faculty candidates, participating in outreach activities, and assisting with student orientation. The undergraduate majors have a dedicated lounge area, and an undergraduate council provides advice to the department chair and serves as a liaison between the chair and the undergraduate majors.

◗ At **Cal Poly San Luis Obispo,** the active SPS chapter helped set up a centrally located physics majors' lounge area called "h-bar." This space provides an area where informal faculty-student interactions and student-student interactions can occur. Students tutoring other students also use this room. The area has ample whiteboard space and is adjacent to the project rooms where seniors have workspace for their research activities. Students—from first-year students to seniors—attested to how they make use of this space for study groups, how the more senior students help the less experienced ones, and how the room led to remarkably high community spirit.

Mentoring for New Faculty

Most college and university faculty members start their teaching careers with little or no training in teaching. They may have served as teaching assistants while in graduate school, but particularly in the sciences, may have had no "full responsibility" teaching. As they take up their first full-time academic positions, they are hit with a wide range of unexpected responsibilities: managing grading and record-keeping for a large class, dealing with student complaints, training their own teaching assistants as well as organizing a syllabus, preparing lectures and labs and writing and grading exams. At the same time, they are working hard to get their research programs up and running. It comes as no surprise that most new faculty find the first years of teaching some of the most stressful and demanding of their academic careers. All of the thriving departments we visited had some means for working with new faculty to help them through this difficult period. Some departments had formal mentoring programs, pairing the new faculty member with a more experienced faculty member. Some sent their new faculty members to the AAPT-APS-AAS-NSF New Physics and Astronomy Faculty Workshops, held each fall at the American Center for Physics. In some departments, the chair played the role of mentor. Some colleges and universities had Teaching and Learning Centers, which provided advice and feedback for faculty. None of the thriving departments simply threw new faculty members into the turbulent waters of teaching and expected them to learn to swim on their own. In most of the departments new faculty were invited to talk about their teaching with more experienced faculty and felt comfortable doing so: not only about a good way to teach projectile motion, but how to deal with a depressed student who has stopped coming to class or what to do with an overly enthusiastic male student who tends to dominate his lab group. This sense of collaboration on teaching occurred with the full knowledge that faculty colleagues will need to make recommendations for reappointment, promotion, and tenure based on the new faculty member's teaching record.

◗ The head of the physics department at the **Colorado School of Mines** sends each of the new faculty members to the New Physics and Astronomy Workshops. The head has lunch with junior faculty regularly. When the new faculty members are assigned to teach the introductory courses, they first serve as "apprentices" with more senior faculty. The department has a "PET" (Peer Enhancement of Teaching) program in which new teachers trade classroom visits with experienced colleagues.

◗ At **Cal Poly San Luis Obispo,** the new physics faculty members are introduced to a clear set of metrics (the "Bailey list") based on a principle of "occasional external validation" against which their performance is to be measured. The presence of these clear guidelines helps provide a comfortable and "transparent" environment in which all faculty members feel free to focus upon the issues of quality instruction.

Informal Student/Faculty Interactions

We have mentioned already several ways in which informal student/faculty interactions occur. In addition to the usual array of departmental picnics and pizza parties, our site visits taught us about informal hallway conversations, informal talks by faculty about the department's research program, and an open-door policy for faculty, who encourage students to drop by for questions at any time. It is through these informal interactions that the faculty get to know their students more personally and the students get to know the faculty as people who have lives and interests outside the classroom. These personal interactions allow the faculty to give the students better academic and career advice. They also make the students more comfortable in approaching the faculty members with questions about physics, careers, and about life.

◗ The **SUNY Geneseo** physics majors participate in an annual bridge-building contest and a Physics Bowl attended by all the physics faculty members. The department maintains an "open door" policy and faculty members are available to talk to students about physics (even in courses they are not teaching), careers, personal issues and so on, at almost any time. Picnics, the Sigma Pi Sigma induction banquet, a junior-senior dinner in the spring, and a commencement luncheon provide opportunities for physics majors to interact with faculty and their families.

◗ At **Harvard,** the physics faculty have lunches at the Harvard Faculty Club for their majors as well as fall and spring departmental picnics. A former chair hosts a weekly physics study night in one of the student houses (dormitories). The undergraduate majors join the graduate students for an annual "puppet show," put on to "roast" the physics faculty.

Alumni Relations

All of the site visit departments keep in touch with their alumni. This contact serves several purposes:

- The alumni provide important feedback to the department about the strength and weaknesses of its undergraduate program as the students pursue a wide range of careers.
- The alumni serve as vivid examples of what careers can be pursued with a physics major. These examples are often important in convincing beginning students and their parents that majoring in physics will provide the students with a good background for many interesting careers.
- The alumni are often good sources of contacts for opportunities for research, internships, and jobs for the department's students.
- The alumni are often good speakers for departmental colloquia, particularly for areas outside of basic research.
- By tracking alumni career trajectories, the department has a much more realistic sense of its students" interests and how a physics major can help them to pursue those interests.

◗ In the lobby near the **SUNY Geneseo** physics department office hangs a map of the United States overlaid with photos of recent physics alumni and brief captions indicating where they are employed or the graduate school they are attending. Students at Geneseo cited this map as giving them good information about the wide range of careers possible with a physics major.

◗ At the **Colorado School of Mines,** the Department of Physics maintains an active "Visiting Committee" composed of representatives from local industry, research university faculty, and recent CSM alumni. The department also keeps in contact with alumni through a survey inspired by the Accrediting Board for Engineering and Technology (ABET) and an annual newsletter.

◗ The SPS chapter at **Bethel College** sponsors two or three talks each year by alumni working in local industry. Many local alumni also attend the annual SPS banquet. This network of alumni provides many opportunities for student internships during the summer and part-time work during the academic year.

Physics Education Research

Physics education research (PER) is a growing branch of physics research that focuses on studies of student learning and problem solving, as well as on applying findings from learning research to the development of curricular materials. Physics is considerably ahead of all the other sciences in having substantial literature on student learning and problem solving. The recent report by the National Research Council, *How People Learn: Brain, Mind, Experience and School* (1999), and a recent review of PER by McDermott & Redish (1999), highlight many of the salient findings in PER. For example, research on learning strongly suggests that active engagement on the part of students is more conducive for knowledge acquisition, recall, and conceptual understanding than more passive approaches [Bransford, Brown and Cocking, 1999]. This research has in turn led to the development of pedagogical techniques that get students more actively involved in learning physics. See, for example [Mazur, 1997], [Mestre, *et al.*, 1997], [Sokoloff and Thornton, 1997], and [Thornton and Sokoloff, 1998].

Yet, despite the progress that PER studies have brought in understanding teaching and learning, there appears to be some controversy in the physics community about the implications of PER. The controversy arises because of some of the dogmatic interpretations (really, from our point of view, misinterpretations) of the results of PER. For example, the well-documented role of interactive-engagement techniques in enhancing students' conceptual understanding of physics could be misinterpreted as saying that there is no role for the traditional lecture in physics. The true lesson, we believe, is the following: Know your students. For some students, lecturing is just fine. They will do the interactive-engagement work on their own in small study groups, for example. For other students, a mix of lecturing (which is what they expect to find in science courses) and interactive-engagement methods is best. For yet other groups, hands-on interactive-engagement without much lecturing might be the preferred mode. In all cases, knowing your students and getting feedback about what works with those students are the key features.

All of the site visit departments had some (but by no means all) faculty members who were aware of the findings of physics education research. This awareness came about through reading articles in *The American Journal of Physics* and *The Physics Teacher*, by attending meetings of the American Association of Physics Teachers, by participating in the NSF-funded New Physics and Astronomy Faculty Workshops, or by inviting faculty actively engaged in PER to give talks to the department. Most of the site visit departments were experimenting with modes of pedagogy suggested by PER as effective in enhancing student understanding of physics, but none had completely forsaken traditional lectures. Nor had any adopted wholesale the curricula that have been developed and tested by PER faculty. We did find, however, a sense of continuous experimentation and evaluation of the physics teaching, particularly in the introductory courses. The students reported enthusiastically about the energy, care, and concern expressed by the faculty in their teaching, while at the same time recognizing that the physics courses were often the most demanding courses on campus. The students sensed that the faculty members were there to work with them and to help them master the skills and develop the understanding necessary to pursue work in physics.

PER References

L.C. McDermott and E.F. Redish, "Resource letter: PER1: Physics education research," *Am. J. Phys* **67,** 755–767 (1999).

E Mazur, *Peer Instruction: A User's Manual* (Prentice Hall Upper Saddle River, NJ, 1997).

J.P. Mestre, W.J. Gerace, R.J. Dufresne, and W.J. Leonard, "Promoting active learning in large classes using a classroom communication system," in E.F. Redish and J.S. Rigden, eds, *The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics Education* (American Institute of Physics, Woodbury NY, 1997), pp. 1019–1036.

John D. Bransford, Ann L. Brown and Rodney R. Cocking, eds, National Research Council, *How People Learn: Brain, Mind, Experience, and School* (National Academy Press, Washington, D.C., 1999).

D.R. Sokoloff and R.K Thornton, "Using interactive lecture demonstrations to create an active learning environment," *Phys. Teach.* **35** (6), 340–347 (1997).

R.K.Thornton and D.R Sokoloff, "Assessing student learning of Newton's Laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula," *Am. J. Phys.* **66,** 338–352 (1998).

◗ **North Carolina State University** has long been active in physics education research. In recent years Project Scale-Up, funded by NSF, has focused on developing means for using interactive-engagement techniques in large introductory courses. At present three sections of the calculus-based introductory physics course use the Scale-Up format. The department has recently hired two additional faculty in physics education research.

◗ As a result of its experience with revising its introductory physics courses, the **University of Illinois** Department of Physics is establishing a physics education group. The initial group includes two current faculty members and three graduate students.

◗ **Rutgers University** recently set up a physics education research group with the hiring of a senior faculty member from another major research university.

◗ The head of the physics department at the **Colorado School of Mines** actively promotes and rewards the use of innovative pedagogy at all levels of the curriculum, and most faculty are trying new pedagogy in their courses. Faculty members are encouraged to seek external funding to support pedagogic reforms.

Counter-Examples

The Task Force did visit two physics departments whose undergraduate programs turned out not to be as “thriving” as we had anticipated based on our preliminary information. We decided not to include them in the series of case studies. They do, however, form a small, but useful set of “control group” departments. These departments were by no means “bad” departments, but for a variety of reasons their undergraduate programs were not very successful. One, a large research university, graduates about 20 majors per year, but upon closer examination, we discovered that the relatively large number of majors was due primarily to the efforts of two, non-tenure-track faculty members close to retirement. Such a program is not sustainable. The other department was in a university that serves a large minority population. The department was quite successful in establishing a substantial graduate program and building up research efforts by most of the faculty. However, the focus on getting the research program established had siphoned energy away from the undergraduate program, which also suffered from lack of support in the administration. Since the site visit, several faculty members in the department have begun planning actions to revitalize (or in this case, vitalize) the undergraduate program.

Both of these counter-examples demonstrate the importance of having a clear focus on undergraduate physics and developing broad support and engagement in the undergraduate program by a substantial fraction of the department’s faculty. Both these departments have the raw material for thriving undergraduate physics programs, but they lacked the focused leadership and widespread engagement by the faculty required to shape that raw material into an effective program.

Chapter 5.
The Survey

Background

Recognizing that our site visits to 23 institutions (representing 3% of the undergraduate physics programs in the United States) may not have given us a complete or representative overview of the state of U.S. undergraduate physics, we sought to augment our conclusions from the site visits with results from a survey that would provide a more complete view of the status of undergraduate physics education. To accomplish this result, the Task Force composed a survey form (see Appendix VII) to distribute to all undergraduate programs in the United States. Its goals were to provide data of greater statistical reliability than those obtained from the site visits, to give a more detailed and comprehensive snapshot of undergraduate physics programs, and to reveal trends or circumstances that might have been missed in the site visits. The distribution of the survey form and the analysis of the responses were done with the collaboration of the Statistical Research Center of the American Institute of Physics.

The survey form, which sought to gather information about curricula, recruiting, advising, alumni contacts, and reform efforts, was posted on a website. Chairs of all 759 undergraduate programs were notified on April 17, 2002, and asked to participate in the survey. They were told that the survey results would be analyzed only statistically and that we would not identify any of the respondents in our publications. Follow-up reminders were sent to nonrespondents on April 29, May 22, and June 5. Data gathering closed on June 17, at which time 561 replies had been received, representing 74% of the programs surveyed. This represents an extraordinarily high response rate, which typically indicates that the questionnaire focused on issues of concern to the respondents.

Originally there was concern that the response would not represent a fair cross-section of the undergraduate programs; we feared that small or inactive departments would be less likely to respond, as they have little to report. Tables 1 and 2 compare the response rates according to number of faculty and according to number of graduates (totaled over the three years 1998–2000). Data on department size and number of graduates in Tables 1 and 2 were collected independently by the AIP Survey Research Center as part of its regular annual survey of physics programs.

The results summarized in Tables 1 and 2 demonstrate that our fears of a skewed response rate were not justified. Table 1 shows that the survey response rate was quite constant independent of faculty size. Table 2 shows that the response rate was constant independent of number of graduates and also independent of highest degree awarded. Based on the analysis of these three factors (faculty size, number of degrees awarded, and highest degree awarded), the response rates appear to be free of bias in any particular direction. Small deviations between different categories can be ascribed to statistical fluctuations and are generally within the anticipated statistical sampling errors.

Table 1. Survey response rate according to size of department (number of faculty)

Number of faculty (FTE)	Number of departments by highest degree			Total number of departments	Response rate %
	B.S./B.A.	M.S.	Ph.D.		
≤ 2.0	95	—	—	95	67
2.1 – 3.0	87	1	—	88	73
3.1 – 4.0	87	1	—	88	78
4.1 – 6.0	108	4	2	114	71
6.1 – 9.0	80	18	8	106	73
9.1 – 15.0	34	33	27	94	83
15.1 – 25.0	5	10	57	72	74
25.1 – 39.9	4	3	46	53	81
≥ 40.0	—	—	33	33	70
Total number of departments	500	70	173	743	74

Table 2. Survey response rate according to number of bachelor's degrees awarded (1998–2000 total)

Number of bachelor's degrees (3-year total)	Number of departments by highest degree			Total number of departments	Response rate %
	B.S./B.A.	M.S.	Ph.D.		
New departments*	11	1	—	12	58
None	22	1	—	23	74
1 to 5	156	10	5	171	71
6 to 9	124	17	21	162	78
10 to 14	92	14	28	134	69
15 to 29	83	25	56	164	76
30 to 44	22	3	28	53	79
45 or more	5	—	35	40	73
Total number of departments	515	71	173	759	74
Total response rate	74	68	77	74	

*These 12 departments were added to the AIP database during the three years 1998–2000.

Courses and Curricula

The first section of the survey dealt with courses and curricula. One of the conclusions from the site visits was that thriving departments were often characterized by a diversity of physics degree programs or "tracks." We sought to use the survey to determine whether that finding, based on a limited number of data points, is broadly characteristic of the physics community. Moreover, we requested information on the alternative degrees and the number of physics credits required.

Of the responding schools, 81% characterized themselves as following the traditional semester system in awarding course credits, 6% awarded credits following a traditional quarter system, 10% awarded credits on an alternative system with one credit per course, and 3% followed various other schemes for awarding credits. We asked each school to begin by providing information about its "standard" physics program. This is usually the most rigorous program, requiring the greatest number of physics credits and often designed to prepare students for graduate study or professional work in physics. Table 3 shows the survey results for the number of physics credits required for this degree program compared with the total number required for a bachelor's degree.

Table 3. Credits required for "standard" physics degree

Academic Calendar	Total credits for bachelor's degree		Physics credits for "standard" degree		Number of respondents
	Low	High	Low*	High*	
One credit per course	30	36	8 (25%)	12 (39%)	57
Semesters	110	146	32 (25%)	50 (40%)	452
Quarters	175	196	54 (29%)	87 (48%)	30

*Low and high figures represent 10% and 90% range; that is, 10% of the respondents are below the low figure and 10% are above the high figure. The numbers in parentheses represent the fraction of the total credits represented by the required physics credits.

Institutions vary in terms of the number of total credits required for a baccalaureate degree, and they vary in terms of the proportion of those credits that must be completed in physics to be awarded a physics degree. The physics fraction of total graduation credits required for the "standard" physics degree is typically in the range of 25–39% for schools on the one credit per course system, 25–40% for schools on the traditional semester system, and 29–48% for schools on the traditional quarter system. Thus, to earn a physics degree, virtually all physics departments require that at least 25% of all credits be taken in physics and comparatively few departments require more than 40%.

We also surveyed the physics credits required for different types of "standard" degree programs. Table 4 shows these data, along with the corresponding mathematics and chemistry requirements for the "standard" degree program.

Our site visits indicated that thriving departments often involved students in research experiences or required a thesis based on a research or library project. Our survey indicated that a research experience is required by 36% the schools in which the "standard" physics program is a

B.S. in physics, 29% in which it is a B.A. in physics, and 37% of the other bachelor's program. Similarly, a thesis is required in 14% of the B.S. programs, 19% of the B.A. programs, and 17% of the other programs. Perhaps surprisingly, the research and thesis requirements were more common in B.A./B.S. institutions (28% and 13%, respectively) than in Ph.D. institutions (21% and 9%).

Table 4. Physics, mathematics, and chemistry requirements in "standard" degree programs

"Standard" physics degree program	Physics credits required*		Mathematics credits required*		Chemistry credits required*		Number of respondents
	Low	High	Low	High	Low	High	
B.S. in physics	27%	41%	10%	18%	3%	8%	413
B.A. in physics	23%	37%	6%	16%	3%	9%	100
Other bachelor's	22%	40%	7%	17%	4%	9%	32

* Credits are given as a percentage of the total credits required for the degree. Low and high figures represent 10% and 90% range; that is, 10% of the respondents are below the low figure and 10% are above the high figure. Fifty-six percent of the B.A. programs and 22% of the B.S. and other bachelor's programs require no chemistry; the table shows the typical ranges only from the respondents who require chemistry.

The B.S. is by far the most common "standard" degree program: It is identified as the "standard" degree by 71% of institutions in which the bachelor's is the highest degree, 90% of M.S. institutions, and 84% of Ph.D. institutions. The B.A. is the "standard" degree at 23% of the bachelor's institutions, 2% of the M.S. institutions, and 11% of the Ph.D. institutions. Other degrees identified at 6–8% of institutions as the "standard" program include a bachelor's in engineering physics (2% of all institutions) and a bachelor's in applied physics (2% of all institutions).

For the various "standard" tracks, we asked institutions to report the number of credits required for various courses in the physics curriculum. These data are still under analysis to correct for variations in systems of assigning credits.

Table 5 shows the alternative degree tracks offered by institutions with various "standard" physics degree programs. Overall, 84% of departments offer at least one alternative degree track. We asked institutions to specify the number of physics credits required in their various alternative tracks and to list the number of students who completed degrees in the past three years under the alternative tracks. These data proved difficult to analyze, so it may be necessary to do follow-up surveys to selected departments to complete the correlation between the availability of alternative tracks and the number of physics graduates.

Table 5. Fraction of reporting departments offering alternative physics degree tracks for various "standard" programs

Alternative degree track	"Standard" physics degree program			Overall fraction %
	B.S. in physics %	B.A. in physics %	Other bachelor's %	
B.A.	46	n/a	28	39
Physics degree for teachers	30	24	28	29
Specialized degree (e.g., geophysics)	17	13	14	16
Applied physics	16	6	17	14
Engineering physics	15	6	17	13
Combined degree (e.g., physics + math)	11	11	28	12
Astronomy degree	7	11	—	7
Other	20	18	24	20
No alternative track	12	35	24	16
Number of responding departments	368	80	29	477

Questions concerning the availability of minors did not yield any surprising results. Of the reporting departments, 90% offer a minor in either physics (75%), astronomy (1%), or both (14%). As might be expected, the departments with the largest numbers of minors are also those with the largest number of majors. However, the overall numbers are relatively small—only 16% of reporting departments awarded an average of more than two minors per year in physics or astronomy during the past three years. While virtually all physics departments offer minors, there are cultural differences in the extent to which this option is stressed. By way of example, some of the research departments that award very large numbers of physics bachelors annually award no minors in physics. Conversely, some of the smaller bachelors-granting departments award more minors in physics annually than they do bachelors in physics.

Finally, the responders were asked an open-ended question about whether their institutions were planning to add any alternative degree tracks in the near future. Most responders did not answer this question, which we take to suggest that they are not planning to add new tracks. Of those who did respond, the most frequent answers were "no" (156 responses) and "maybe" (29). Other frequently cited responses were engineering (28), teaching (13), applied physics (12), computational physics (11), medical physics (11), and astronomy (9). Other responses included biological physics, materials physics, physics for pre-law, and geophysics.

Recruitment Activities

Question 8 on the survey form asked departments to specify which recruitment activities they pursue. Responses (from 561 departments) were as follows:

Recruiting high school students

Host prospective students and their families in the department	60%
Hold annual departmental open house for students and parents	47%
Recruit high school students likely to major in physics	34%
Faculty and students regularly visit local high schools	24%
Hold summer workshops for high school students	14%
Recruit high school students who are underrepresented minorities	11%

Recruiting enrolled college students

Identify and recruit talented students in service courses	61%
Group potential physics majors in special section of intro course	22%
Offer "introduction to the profession" courses for first year students	15%
Actively recruit transfer students from two-year colleges	11%

The right-hand column adds to more than 100% because departments were asked to indicate all recruiting activities in which they took part.

As might be expected, there is a correlation between the number of recruiting activities and the size of the department. Departments in which the highest degree is the bachelor's reported an average of 2.7 recruiting activities, while Ph.D.-granting departments reported an average of 3.9 recruiting activities. Of the 113 departments reporting 0 or one recruiting activities, 68% had six or fewer faculty; conversely, of the 122 departments reporting five or more recruitment activities, 71% had more than six faculty.

The correlations between recruitment activities and number of degrees awarded are shown in Tables 6 and 7 for departments in which the highest degree is respectively the bachelor's and the Ph.D. Table 6 indicates that, of the bachelor's-granting departments, 50% of those that engage in the fewest recruiting activities (0 or one) awarded fewer than two degrees per year over the three-year period. At the other end of the scale, the correlation is much weaker—of the departments that engaged in the highest number of recruitment activities (four or more), fewer than half exceed the average number of degrees (three/year) awarded by baccalaureate departments.

For the Ph.D.-granting departments (Table 7), the correlation between the number of graduates and the number of recruitment activities is weak at best. Sixty percent of the departments with five or more recruiting activities fail to reach the average of 10 graduates per year that characterizes the Ph.D.-granting institutions, and a third of the departments with the smallest number of recruiting activities exceed the average.

Table 6. Effect of number of recruitment activities on three-year total of physics bachelor's degrees at baccalaureate institutions

Three-year total of bachelor's degrees	Number of recruitment activities					Overall fraction of departments
	≤ 1	2	3	4	≥ 5	
0 to 5	50%	38%	26%	27%	23%	35%
6 to 9	23%	24%	26%	29%	30%	26%
10 to 14	12%	20%	19%	17%	25%	18%
15 or more	15%	18%	28%	27%	21%	21%
Number of responding respondents	100	81	91	52	56	380

Table 7. Effect of number of recruitment activities on three-year total of physics bachelor's degrees at Ph.D.-granting institutions

Three-year total of bachelor's degrees	Number of recruiting activities			Overall fraction of departments
	0 to 2	3 to 4	≥ 5	
0 to 14	27%	28%	28%	28%
15 to 29	42%	37%	32%	36%
30 or more	31%	35%	40%	36%
Number of responding departments	26	57	50	133

Another open-ended question asked departments to specify which of their recruiting activities they considered to be most effective. The most frequent response (which was not given among the original choices) was to assign good teachers to the introductory courses (cited by 29 responders). Other frequently mentioned successful activities included hosting of prospective students, recruiting talented students from the introductory course, high school recruitments, and open houses. Less frequently cited responses (fewer than 10) included special programs or courses, recruitment by the admissions staff, scholarships, telephone contacts, web or email contacts, mailings or brochures, SPS activities, and research opportunities.

Interactions between Faculty and Students

Among the measures of satisfaction most often mentioned by students during our site visits were advising and the informal interactions between students and faculty. Our survey sought to gather additional information on the number and type of these interactions and their correlation with the number of majors.

Overall, most institutions assign several faculty members as undergraduate advisors. A significant number, however, use only a single faculty member (or the department chair) as the undergraduate advisor. Curiously, this distinction correlates inversely with the size of the institution and is mostly independent of the number of majors. Multiple faculty members handle the advising in 75% of bachelor's institutions, 41% of M.S. institutions, and 51% of Ph.D. institutions, while a single faculty member handles the responsibility in 22% of bachelor's institutions, 55% of M.S. institutions, and 41% of Ph.D. institutions. Multiple faculty do the advising at 74% of schools with four or fewer faculty, 80% of schools with 4.1–9 faculty, 46% of schools with 9.1–25 faculty, and 59% of schools with more than 25 faculty; a single faculty member (possibly the department chair) is assigned to the advising in respectively 24%, 18%, 49%, and 27% of schools in these categories. Multiple faculty members do the advising in 67% of schools with an average of fewer than two graduates per year and also in 67% of schools with an average of more than 10 graduates per year, while a single faculty member does the advising in 27% of schools with an average of fewer than two graduates per year and in 23% of schools with an average of more than 10 graduates per year. (A small number of departments use a nonfaculty advisor in the physics department or a university advisor outside of physics.)

Responses regarding the frequency of student-advisor interaction varied from at most once per year to several times per term. Overall 62% of institutions reported that interactions occurred several times per term, with the bachelor's institutions ranging somewhat higher (70%) and the Ph.D. institutions lower (42%). As might be expected, those institutions using multiple faculty advisors were more likely to report several interactions per term (72%) than those using a single faculty member (25%). Unfortunately, during the site visits we did not ask students about the frequency of their interactions with their advisors; it would have been interesting to verify whether the data provided by the department head is "wishful thinking" or reality.

Question 11 of the survey form asked departments to indicate which of a list of activities they engaged in to make their students feel a part of the department. Responses were as follows:

Have an active physics club or SPS chapter	76%
Provide a dedicated undergraduate study room or lounge	74%
Provide building keys to undergraduate majors	52%
Conduct exit interviews with graduating seniors	43%
Assign a faculty mentor to each student	43%
Assign a peer mentor to each student	2%
Other activities	32%

Ph.D.-granting departments tended to run 10–20% above these averages, while bachelor's-granting departments tended to run about 10–20% lower. There was a similar correlation with the size of the department, with 53% of departments having three or fewer faculty engaging in two or fewer of these activities, while 68% of departments with 25 or more faculty engaged in four or more activities.

How do these activities correlate with the department's success in attracting and retaining majors? Tables 8 and 9 display the correlations for bachelor's-only institutions and Ph.D.-granting institutions, respectively. Here the correlations appear to be much stronger than was the case for the correlation between recruitment and number of majors (Tables 6 and 7). It seems clear that departments should focus their efforts on improving these interactions rather than on recruitment. This is consistent with strong anecdotal evidence obtained in conversations with students during the site visits—many students reported switching from engineering or math to physics because the physics department presented a more welcoming and accommodating image.

Table 8. Effect of number of departmental interactions on three-year total of physics bachelor's degrees at baccalaureate institutions

Three-year total of bachelor's degrees	Number of departmental interactions					Overall fraction of departments
	≤ 1	2	3	4	≥ 5	
0 to 5	19%	26%	30%	21%	5%	35%
6 to 9	13%	27%	24%	21%	16%	26%
10 to 14	11%	18%	35%	20%	17%	18%
15 or more	5%	18%	30%	28%	18%	21%
Number of responding respondents	48	85	107	81	48	370

Table 9. Effect of number of departmental interactions on three-year total of physics bachelor's degrees at Ph.D.-granting institutions

Three-year total of bachelor's degrees	Number of departmental interactions			Overall fraction of departments
	0 to 2	3 to 4	≥ 5	
0 to 14	36%	50%	14%	28%
15 to 29	17%	49%	34%	36%
30 or more	15%	52%	33%	36%
Number of responding departments	29	65	37	131

The availability of career information represents another area in which outreach by the department can enhance the student experience, both to attract majors and to help launch imminent graduates toward the next stage of their professional careers. Question 12 of the survey asked departments to list activities undertaken *within the past year* to provide career information to undergraduates. Overall responses were as follows:

Career materials from professional societies	63%
The university career services office	51%
Departmental colloquia by physicists in industry	47%
Alumni visits to the department	45%
Field trips to local industries	25%
Other	26%
None offered	6%

In contrast to the case of departmental interactions, in providing career information the level of activity of bachelor's-only institutions tended to be a bit *above* that of Ph.D.-granting institutions. With the exception of departmental colloquia (which are more common in Ph.D.-granting institutions), the activity level of bachelor's-only institutions in offering career information tended to fall about 10% above these overall averages, while that of the Ph.D.-granting institutions fell about 10% below. The level of activity in this area correlated weakly with the size of the department, with large departments tending to provide a somewhat greater level of career information than smaller departments. It appears from these data that larger, bachelor's-only departments are the most active in providing career information to their majors.

Two open-ended questions were asked in these areas. The first inquired about the department's most successful activities in shaping student attitudes toward the department. The most frequent responses were: informal interactions between faculty and students (cited on 112 forms), undergraduate study room (44), SPS activities (42), research experiences (33), and advising or mentoring (20). The second open-ended question asked about the department's most useful activity in providing career guidance. Responses included: faculty advising (55 citations), alumni visits (31), colloquia (18), research opportunities (15), career service office (10), and career materials from professional societies (9).

Alumni Tracking

Of the 561 responses to the survey, 453 reported answers to question 13, which asked about the career destinations of graduates of the past three years. Table 10 compares the responses from the three types of institutions. It should be noted that these data are given by number of responses and are NOT weighted by the number of graduates.

Table 10. Reported alumni destinations (as percent of responses) by highest degree awarded by institution.

Alumni destination	Highest institutional degree			Overall %
	B.S./B.A.	M.S.	Ph.D.	
Graduate school in physics	31	38	43	35
Other graduate school	15	7	12	14
Continue in 3/2 engineer. prog.	11	6	1	8
Employed in technical field	22	28	21	22
High school teaching	8	7	4	7
Employed in nontechnical field	3	2	3	3
Active military	2	1	2	2
Other	2	3	2	2
Don't know	7	8	13	9
Number of responding departs.	300	42	111	453

The data in Table 10 agree reasonably well with the data collected in the AIP Survey Research Center's annual survey of physics departments, which in recent years indicates that 32% of graduates enter graduate programs in physics, 20% enter graduate programs in other fields, and 48% enter the workforce.

Question 14 asked departments to identify activities they used to keep in contact with their alumni. With one exception, responses varied little among B.A./B.S., M.S., and Ph.D. institutions. Overall responses were:

Updates from past students by email and phone	51%
Mailing or email addresses from students at graduation	46%
Information on employment or graduate school plans at graduation	45%
Mailing list for departmental newsletter	26%
Surveys of alumni	24%
Other	4%
None of the above	32%

The one case in which there was a significant variation among types of institutions was in that of the departmental newsletter, for which 45% of Ph.D. institutions indicated that choice but only 20% of B.A./B.S. institutions.

Curricular Reform

More than 60% of the reporting departments (342 out of 561) affirmed that they had made “significant” changes in curriculum in the past several years. The overall responses to specific areas of change were as follows: upper-division courses—71%; calculus-based introductory courses—70%; general education courses—56%; introductory courses for majors—51%; algebra-based introductory courses—42%. Among the three types of institutions (B.S./B.A., M.S., Ph.D.), B.S./B.A. institutions were more likely than Ph.D. institutions to have made changes in their upper-division courses (76% vs. 60%) and general education courses (60% vs. 44%), while Ph.D. institutions were more likely than B.S./B.A. institutions to have made changes in calculus-based introductory courses (75% vs. 69%) and introductory courses for majors (64% vs. 47%).

It was more common for departments to report reforms in both content and pedagogy than in either area alone; the fractions of the reforms involving both content and pedagogy ranged from about 60% in general education courses, to 50% in introductory courses for majors, to 40% in calculus-based introductory courses and upper-division courses, and to 30% in the algebra-based introductory courses. Changes involving content only were most common in the upper-division courses (40%) and rather rare for introductory courses (10–20%). These data are not surprising, in that departments often introduce new courses for majors and rarely alter the traditional curriculum of the introductory courses. Changes in pedagogy more commonly occurred at the introductory level (80–90% of the changes involved pedagogy, either alone or in concert with changes in content) than at the advanced level (56%). There was relatively little systematic variation across institutional types in these data.

These results paint an encouraging profile of the state of undergraduate physics education and suggest a greater widespread receptiveness for curricular change than had been anticipated before the survey (although we must admit that we left it to the departments to determine for themselves what is a “significant” curricular reform).

The most common funding mechanism for curricular reforms was by far the internal reallocation of resources within the department. Overall 63% of those who reported curricular changes indicated this as a source of funding. (Responders were free to indicate several sources.) Among institutional types, these responses ranged from 57% at the B.S./B.A. institutions to 76% at the Ph.D. institutions, presumably because the latter often have more resources to reallocate. Other sources of funding were university or endowment funds from outside the department (27%), grants from NSF or other federal agency (22%), grants from private foundations (9% overall, but more common at B.S./B.A. institutions than at Ph.D. institutions), funds or equipment from business or industry (4%). Except as noted above, there was little variation across institutional types in these responses. It should be especially noted that the share from the federal agencies remains relatively flat across institutional types, indicating that the large research institutions are clearly not dominant in the quest for federal funding for curricular reform (although the dollar-weighted funding averages might be skewed in that direction).

We also asked three open-ended questions about the curricular reforms. Regarding the source of the motivation of the reforms, by far the most common response was energetic individual faculty members (112 responses). The next most common reform motivation was the desire to improve courses (41 responses), followed by college-wide initiatives (26), responses to external reviews (18), responses to student feedback (18), the desire to recruit more majors (16), internal reviews (15), and the development of new programs (11). "Negative" motivations (threats from the dean, reduction in faculty size) were cited only rarely (respectively, eight and five responses). The impact of physics education research was cited only three times, although that may have been an indirect motivation in driving the "energetic individual faculty members" to undertake the reform efforts.

The most common response to our inquiry about what the reforms were intended to accomplish was attract more majors (71), although content-related issues (better understanding of topic, better preparation for graduate school, better courses, better preparation for work force) drew significant responses as well (respectively 48, 47, 40, 25).

It appears that departments undertake these changes with only vague ideas of assessment. Our query regarding indicators of success drew "none" as its most common response (59), although student attitudes (43), increased number of majors (40), and increased enrollments (21) were also cited. Only 39 responses mentioned a formal assessment mechanism such as the Force Concept Inventory exam or the Graduate Record Examination.

Overall Evaluations of Undergraduate Physics Programs

Our survey concluded with open-ended questions about the undergraduate program's greatest strengths and greatest needs or challenges. Individualized faculty attention to students was the overwhelming choice for the greatest strength (203 responses). Next most often cited responses were research opportunities (89), excellent curriculum (79), and quality of faculty (70). Few departments cited flexible major programs (17) or an active SPS chapter (3) among their strengths; this is rather surprising in view of the survey results showing that 84% of departments offer alternative tracks to the major and 76% of departments regarded their SPS chapter as a major factor in promoting a welcoming attitude toward students. Only 15 departments cited their excellent equipment as one of their greatest strengths.

By far the greatest challenge seen by most department heads is the need for more students (204 responses). The need for resources is next most commonly cited, including more faculty (73), improved lab equipment and space (41), increased funding (39), increased administrative support (17), improved research opportunities (20), and better facilities and more space (13). Improved quality is also a significant need, including courses (38), faculty quality (17), better student preparation in math (20), and better students (9). Sadly, increased minority representation drew only five responses.

Chapter 6.
Connections, Lessons, and Other Issues

In the previous sections of this report, we have laid out our analysis of what makes a thriving undergraduate physics program. That analysis has been backed up with evidence and examples. In this section, we take a somewhat more subjective approach to look at connections between our analysis and work done by others. We also write about some new questions that have arisen as part of our study and implications of those questions for the future of physics.

Undergraduate Mathematics Site Visits

After this study was well under way, we learned about a similar effort in undergraduate mathematics education. (That in itself says a lot about how poorly the scientific and mathematics communities communicate the results of such studies.) In the early 1990s, the Mathematical Association of America, with funding from the National Science Foundation, carried out a series of 10 site visits to undergraduate mathematics programs. Although the mathematics site visit group used a methodology somewhat different from that used by SPIN-UP, the conclusions expressed in the report *Models that Work: Case Studies in Effective Undergraduate Mathematics Programs* [Tucker, 1995] are quite consistent with the results we have found from the SPIN-UP site visits. The MAA group selected departments based on evidence of effective practices excelling in

- attracting and training large numbers of mathematics majors, or
- preparing students to pursue advanced study in mathematics, or
- preparing future school mathematics teachers, or
- attracting and training underrepresented groups in mathematics.

On p. vii the report states, "The site visits revealed that there is no single key to a successful undergraduate program in mathematics. Almost any approach can be made to work in almost any institutional context if a substantial number of the mathematical faculty care deeply about undergraduate education, create an atmosphere among faculty and students that the study of mathematics is important and rewarding, and maintain close interactions with their students." This finding agrees with what SPIN-UP found in the 21 physics site visit departments.

The MAA report goes on to delineate the common features of effective programs (p. 3) including three states of mind that underlie faculty attitudes in effective programs:

- respecting students, and in particular, teaching for the students one has, not the students one wished one had.
- caring about the students' academic and general welfare.
- enjoying one's career as a collegiate educator.

"A common theme of effective programs is the existence of a variety of mechanisms for interactions between faculty and students outside of class, both in one-on-one settings and in social groups." (p. 3) The effective departments also exhibited:

- a curriculum geared toward the needs of the students not the values of the faculty
- an interest in using a variety of pedagogical and learning approaches.

The site visit committee identified four major components of efforts to reform mathematics education: (p. 32)

a. Assessing the goals of the current program and aligning them with the needs of the students.

b. Building support for innovation that engages the faculty. (Some efforts start with broad support within the department, others are initiated by a few energetic individuals.)

c. Initiating the process of change and experimentation. Continuing experimentation was the hallmark of most of the institutions visited in this report, even though they already had successful programs.

d. Developing an environment of faculty involvement in the welfare, academic, and otherwise, of their students.

All of these statements closely mirror the results found in the SPIN-UP site visits. Our conclusion is that the features of effective undergraduate programs apply to all the science, technology, engineering, and mathematics disciplines.

Revitalizing Undergraduate Science Education

Sheila Tobias has been studying science and mathematics education for more than a decade. Her book *Revitalizing Undergraduate Science Education* (Research Corporation, Tucson, AZ, 1992) reports on a series of case studies in undergraduate chemistry, physics, and mathematics programs that "work." Tobias's conclusions neatly parallel those in this SPIN-UP report. Here are some selected conclusions:

> "…first, change is not implemented by experts, but originates in local commitment and reallocation of resources at the midlevel of management—in the case of colleges and universities, the department." (p. 158)
>
> "A hallmark of effective programs is that the process of reform is all-engaging. Ideas are solicited from faculty and implemented locally by the department." (p. 158)
>
> "The model for science education reform is not an experimental model, not even a research model, but a *process model* that focuses attention continuously on every aspect of the teaching-learning enterprise, locally and in depth…. In programs that work, faculty members pay continuous attention to 'what we teach, who we teach, and how we teach.'" (p. 160)

Thriving in the Business World

Parallels to our report's conclusions are also found in the vast business literature on managing change and building thriving companies. As one recent example, we cite Jim Collins's *From Good to Great* (HarperCollins, New York, 2001), which analyzes a number of companies that have successfully made the transition from being "good" to being "great." Collins and his research team identified a number of characteristics shared by these companies and missing in those companies that failed to make the transition. Again, a few selections show the parallels:

> "All good-to-great companies began the process of finding a path to greatness by confronting the brutal facts of their current situation…. The good-to-great companies faced just as much adversity as the comparison companies, but responded to that adversity differently. They hit the realities of their situation head on." (p. 88)
>
> "Good-to-great transformations often look like dramatic, revolutionary events to those observing from the outside, but they feel like organic, cumulative processes to people on the inside. The confusion of end outcomes (dramatic results) with process (organic and cumulative) skews our perception of what really works over the long haul. No matter how dramatic the end result, the good-to-great transformations never happened in one fell swoop. There was no single defining action, no grand program, no one killer innovation, no solitary lucky break, no miracle moment." (p. 186)
>
> "Level 5 leaders [leaders of those companies that have made the transition] are ambitious for the company and what it stands for; they have a sense of purpose beyond their own success." (p. 198)

Underrepresented Groups and the Issue of Diversity

It is a well known but still unsettling fact that women and minorities are distinguished by their lack of presence in the STEM disciplines, particularly in the physical sciences, mathematics and engineering. The National Science Foundation's *Science and Engineering Indicators 2002* gives the detailed statistics. Participation is increasing, but much more slowly than everyone would like. There is much speculation about this lack of participation, and we shall not rehearse those speculations here. The SPIN-UP site visits did uncover one surprise: We had anticipated that thriving departments, which managed to recruit many more students than the national average and which were well regarded within their institutions, would have substantial success in bringing women and minority students into physics. We found that most of the site visit departments did in fact do a bit better than the national average in attracting underrepresented students, but not a lot better. This finding was a surprise to all of the site visit teams because the folklore amongst those who are actively working to increase the participation of underrepresented groups in STEM is that active, supportive programs will be much more successful in attracting women and minority students. Our conclusion is that these conditions may be necessary, but they are not sufficient.

The MAA report [Tucker, 1995] comes to a similar conclusion:

> "Unfortunately, the four-year mathematics programs visited in this project had negligible numbers of Black and Latino mathematics majors, except of course for Southern University and Spelman College, which are historically Black institutions….. The programs that draw large numbers of other types of students apparently need to do something different and special for attracting and retaining this group in mathematics." (page 30)

Faced with these surprising results, the Task Force decided to invite about a dozen representatives of the National Society of Black Physicists and the National Society of Hispanic Physicists to its December 2002 meeting to discuss this issue and to explore possible studies the Task Force might undertake to understand this critical issue more fully. The participants at the meeting concluded that nearly all the general factors that seem to be important for attracting and retaining underrepresented groups in physics are the same factors that attract and retain "traditional" physics students. Nevertheless, these factors do not guarantee that a particular department will attract more students from underrepresented groups. The Task Force plans to use its site visit methodology to study a number of undergraduate physics programs that in fact do serve larger numbers of minority students. Many of these, of course, will be historically black colleges and universities. We also plan to make use of the results of a recent study (Barbara Whitten, Colorado College) that focused on physics departments that have a large fraction of women physics majors.

We argue that increasing the presence of underrepresented groups in physics is important on two counts: First, it is just the right thing to do. Everyone should have the opportunity to experience the joys (and frustrations) of science and to contribute to the betterment of humankind through science. Second, in the 21st century the population subgroup that has historically dominated science (white males) will shrink both in absolute numbers and as a fraction of the U.S. population. It is difficult, if not impossible, to say precisely how many scientists, engineers, and mathematicians the United States needs, but it is safe to say that number will not decrease from our current needs. We do know that with more scientists and with more diverse backgrounds represented, science is likely to advance more rapidly than it would otherwise. Simply from the perspective of maintaining a vibrant scientific and technological workforce to maintain our economy, our security, and the infrastructure needed to improve the health and environment for all people, we will need to tap the full spectrum of the nation's talent for the next generation of scientists, mathematicians, and engineers.

As a result of the December meeting, the Task Force will carry out two further site visits, one to an historically black college or university and the other to a hispanic-serving institution. The results of those site visits will be reported elsewhere. Some Task Force members and some of the representatives at the December meeting are writing a report on the meeting along with articles to be submitted to various physics publications.

Two-year Colleges

The SPIN-UP study focused on physics departments that offer at least the bachelor's degree in physics. Nationwide, however, many students study physics in two-year colleges, some in preparation for transfer to a four-year institution, some as part of their technology training for a two-year associate's degree. A study carried out by the American Institute of Physics [Neuschatz, et al., 1998] indicates that about half of the nation's pre-service teachers take their science courses at two-year colleges. Two-year colleges play an important role in undergraduate science education. But, the academic organization of two-year colleges is substantially different from that of four-year colleges and universities. Only the largest of the two-year colleges have physics departments. Most employ one or two physics faculty as part of a department of natural sciences. In order to understand the characteristics that make up a thriving physics program at a two-year college, Task Force member Tom O'Kuma (Lee College) and Mary Beth Monroe (Southwest Texas Junior College) developed project "SPIN-UP Two-Year Colleges" that has been funded by the National Science Foundation. Employing a site visit protocol similar to that used for SPIN-UP, the two-year college study will sponsor visits to 10 or so two-year colleges and produce a report analyzing the results of those site visits. The report is expected to be finished during the fall of 2003.

Teacher Preparation

Both the general public and those within the scientific community have been calling for improved preparation for K–12 teachers in mathematics and science. Much of this responsibility must fall on the shoulders of undergraduate science and mathematics programs. We were disappointed to find that most of our site visit departments were not actively engaged in pre-service teaching preparation either at the K–8 or at the high school level. Those that did have programs for teacher preparation were serving relatively few students. Although most of the departments acknowledged that they should be doing more, they cited difficulties working with the School of Education (or its equivalent) and the lack of student interest. Even when pre-service courses were offered, few students (and even fewer physics majors) took them.

The physics professional organizations have recently urged physics departments to take a more active role in both pre-service and in-service work with teachers. With generous funding from the National Science Foundation and the Fund for Post-Secondary Education, AAPT, APS, and AIP have launched the Physics Teacher Education Coalition to develop models of effective programs for pre-service teacher work within physics departments. More information on this program can be found at *http://www.phystec.org*. In addition, the report of a University of Nebraska–Lincoln conference on teacher preparation in physics departments [Buck, Hehn and Leslie-Pelecky, 2000] contains several articles describing what physics departments can do to aid pre-service teachers.

Future Directions

1. The Task Force is now in the process of preparing proposals for activities that will build on the SPIN-UP results. The aim is to work with physics departments that want to "revitalize" their undergraduate physics programs. A trial workshop held at the PKAL Summer Institute June 2002 drew about 65 participants from 20 or so physics departments. In the spring of 2003, the Task Force will carry out a trial "consulting visit" to aid a department

planning the revitalization of its undergraduate program. A proposal for more workshops and consulting visits to reach, say, 150 physics departments, would have a major impact on undergraduate physics in the United States

2. As we mentioned previously, the Task Force will also explore the issues of diversity in physics with the aim of promoting some concrete activities.
3. Plans are under way for a conference on algebra-based introductory physics courses to complement the conference on calculus-based introductory physics.
4. The AAPT Committee on Undergraduate Physics, under the leadership of Steve Turley of Brigham Young University, is undertaking a revision of AAPT's *Guide to Undergraduate Physics Programs*. The results of SPIN-UP will guide these revisions. Physics departments planning new initiatives or preparing for departmental reviews often use this booklet.
5. The Task Force has begun to work with leaders in other STEM disciplines who are focusing on undergraduate education. For example, a member of the leadership of ProjectNEXT, Tom Rishel, attended the 2000 New Physics Faculty Workshop, and we hope to send a member of the Task Force to their next conference. In June 2002, Hilborn and Hehn met with geologists Cathy Manduca (Carleton College), David Mog (Montana State University), and Heather MacDonald (William and Mary) to discuss possible extension of the physics site visit techniques to geology departments and other possible areas of collaboration. There has also been some contact with the American Chemical Society's Committee on Professional Training for a possible joint study of diversity issues.

Final Words of Wisdom and Encouragement

The Task Force on Undergraduate Physics is committed to the improvement of undergraduate physics because undergraduate physics plays an absolutely crucial role in educating the next generation of scientists and engineers, the next generation of K–12 teachers, and the future leaders of our society. We believe that the conclusions drawn from our analysis of the site visits and the general survey provide a blueprint for what is needed to build a thriving undergraduate physics program. The blueprint, however, must be adapted to fit each department's local "zoning regulations" (the students each department serves, the faculty and physical resources available, and the mission of the home institution). But we are convinced that with sustained efforts every physics department can have a thriving program in which students are challenged and supported in their many career and intellectual goals and faculty find great satisfaction in approaching undergraduate physics as a scholarly enterprise worthy of the problem-solving and critical-thinking skills that sustain them as researchers.

References

J.D. Bransford, A.L. Brown and R.R. Cocking, eds., *How People Learn, Brain, Mind, Experience, and School* (National Academy Press, Washington, DC, 1999).

G. Buck, J. Hehn and D. Leslie-Pelecky, eds., *The Role of Physics Departments in Preparing K–12 Teachers* (American Institute of Physics, College Park, MD, 2000).

L.A. Coleman, D.F. Holcomb and J. S. Rigden, “The Introductory University Physics Project 1987–1995: What has it accomplished?,” *Am. J. Phys*. **66,** 124–137 (1998).

M.D. George, S. Bragg, J. Alfredo G. de los Santos, D.D. Denton, P. Gerber, M.M. Lindquist, J.M. Rosser, D.A. Sanchez and C. Meyers, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology NSF 96-139* (National Science Foundation, Washington, DC, 1996).

E. Mazur, *Peer Instruction* (Prentice Hall, Upper Saddle River, New Jersey, 1997).

M. Neuschatz, G. Blake, J. Friesner and M. McFarling, *Physics in the Two-Year Colleges* (American Institute of Physics, College Park, MD, 1998).

G.M. Novak, E.T. Patterson, A.D. Gavrin and W. Christian, *Just-In-Time Teaching: Blending Active Learning and Web Technology* (Prentice-Hall, Upper Saddle River, NJ, 1999).

D. Sokoloff and R. Thornton, “Using Interactive Lecture Demonstrations to Create an Active Learning Environment,” *Phys. Teach.* **35**, 340–346 (1997).

R. Thornton and D. Sokoloff, “Assessing student learning of Newton’s laws: The force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula,” *Am. J. Phys.* **66,** 338–352 (1998).

A.C. Tucker, *Models that Work: Case Studies in Effective Undergraduate Mathematics Programs* (The Mathematical Association of America, Washington, DC, 1995).