Best Practices in Undergraduate Physics

C.Beausang, E.Bunn, M.Fetea, G.P.Gilfoyle, O.Lipan, M.Trawick
Department of Physics, University of Richmond

The list of best practices discussed below comes from *Strategic Programs for Innovations in Undergraduate Physics: Project Report* published in 2003 by the American Association of Physics Teachers (AAPT). It is the result of a project *Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP)* organized by the National Task Force on Undergraduate Physics and supported by the AAPT, the American Physical Society, the American Institute of Physics, and a grant from the ExxonMobil Foundation. In Chapter 4 of the report there is a list of the elements of a thriving physics program. The items below are taken from that list. The relevant chapter is included here in the Appendix. Below we present a summary of the Department's efforts under each category and then go beyond the items in that list.

- **Departmental Leadership** - The Department chairs (Seaborn, Gilfoyle, Beausang, and Fetea) have worked closely and cohesively with the faculty to improve the curriculum, create a thriving research enterprise, and attract new students to the Department. This effort goes back nearly two decades.

- **Mission and Vision** - The mission of the Department of Physics is to prepare our students for graduate, industrial, and other careers, support the other sciences and mathematics, and introduce non-science students to the methods, power, and beauty of physics. As essential part of all these enterprises is a research-rich environment to challenge our students at all levels of physics and develop their skills of independent learning and discovery.

- **Undergraduate Research** - All tenured and tenure-track faculty have active research programs. Five out of six are externally funded by NSF, DOE, NASA, and Research Corporation. Each summer 10-15 students spend about 10 weeks immersed in research in one of the Department's labs on campus or off-site at Yale University, Jefferson Lab, or Berkeley. The current research areas are nuclear and particle physics (theoretical and experimental), cosmology, nanophysics, and biological physics. Facilities include a supercomputing cluster, environmental radiation laboratory, and an atomic force microscope. In the last two years twenty-four different University of Richmond students participated in our summer research programs. During that time Richmond faculty have been co-authors of 60 refereed publications, 5 conference proceedings and our students have made 32 presentations (talks or posters) at national meetings. The future is promising; our faculty are spokespersons on two approved experiments at Jefferson Lab and two NASA missions and are members of strong collaborations at national labs and research universities. We note here the research program, while reasonably successful, is diffuse. Each faculty member works in a different specialty and there have been no collaborative efforts among our faculty in recent years.

- **Introductory Physics Courses** - A tremendous effort has gone into improving and upgrading the introductory physics sequence. Starting from an early version of Priscilla

Laws' *Workshop Physics* manual in 1994, we now have a wide array of experiments (about 150 individual laboratories) to support four different courses in our two-semester introductory sequence (*General Physics 1*, *General Physics 2*, *Atomic and Sub-Atomic Physics*, and *Biological Physics*). All introductory courses are taught in a *Workshop Physics* environment where lab and lecture experiences are integrated into a seamless whole. We continue to develop new laboratory experiences (*Atomic and Sub-atomic Physics* and *Biological Physics* are recent innovations) and use the products of Physics Education Research.

The Department has a long history of offering introductory courses to satisfy the general education requirements for non-science majors. We were the first science department to offer such courses over twenty years ago and for many years they ware a large fraction of our teaching effort. We continue to offer a liberal arts physics course and astrophysics course when staffing permits, but the they no longer make up a large fraction of our curriculum.

- **Substantial Majority of Engaged Faculty** - All of the tenured, tenure-track, and term faculty are engaged in the Department life and participate in seminars, outreach activities, social events, *etc.*

- **Administrative Support** - The administration has provided significant support over the last seven years to update and replace aging equipment and to provide funds for new curricular development. The Department has received about $165,000 from federal and internal sources during that time. As part of the Science Initiative, the physics teaching laboratories have been renovated. A new faculty member in biological physics was hired in 2006 as part of an external grant from the Howard Hughes Medical Institute. A non-tenure-track instructor position was added in 2003.

  Nevertheless, staffing remains a challenge. The laboratory support currently is only half of a person. During the 1990's (when the Department had fewer faculty and facilities) the Department had a full time laboratory manager. We also suffer from 'smallcollegeitis'. Each faculty member works in a different specialty and we have not been able to build strength in any one area. We are vulnerable to 'down' periods when faculty are away on research leave and sabbaticals. We are now in a period where we will not have all faculty on campus for a full year until the 2012-2013 academic year. Last, our contribution to the science general education courses is limited. Without hiring temporary faculty we can only offer about one section per year.

- **Supportive, Encouraging and Challenging Environment and Recruitment** - The Department strives to create an intellectual community that is both supportive and challenging. There is a steady stream of social and academic events from LN2 ice-cream socials to regular seminars by outside speakers. All tenured and tenure-track faculty mentor research students during the summer months and the academic year. There are a number of efforts, large and small, to recruit new students including the Chair's announcement of Laser Tag and Deconstruction Night in each introductory physics class, the Physics Olympics, and letter-writing campaigns directed at incoming students.

- **Advising** - The Chair is the primary adviser for physics majors, but all faculty take an interest in their students career plans.
- **Career Mentoring** - The Department Chair performs this task as part of the advising process, but there is no formal career mentoring. Nevertheless, all faculty advise our students informally.
- **Flexible Majors' Program** - We have revised our Physics major program in recent years. Starting with traditional bachelor of science and bachelor of arts degrees we have added an Interdisciplinary Physics major with Mathematics, Computer Science, Biology, and Chemistry.
- **3/2 Dual-Degree Engineering Programs** - We have started in new dual-degree engineering program with George Washington University, Columbia University, the University of Virginia, and Virginia Tech.
- **Physics Clubs and Common Rooms** - Our Society of Physics Students (SPS) organization has been extremely active over the last three years; twice receiving national recognition from the SPS headquarters. We have maintained a common room for physics students for more than 10 years now. We now have a room with desks, computer, couches, and a kitchenette that is part of the physics office suite (otherwise known as 'Physics Central'). We have also found our students use the upper-level, physics teaching labs as de facto lounges. Those rooms are equipped with combination locks and we give the combination to physics students.
- **Mentoring of New Faculty** - The senior faculty routinely discuss the progress of the junior faculty and have met many times informally to discuss research progress, teaching evaluation, *etc.* These meetings are in addition to the annual institutional review process. We have successfully tenured two faculty in the last year.
- **Informal Student/Faculty Interactions** - There are abundant informal student interactions. Almost all faculty offices are located in 'Physics Central' near the Department office and the student lounge to encourage these serendipitous meetings. We hold social events for physics students several times each semester (LN2 socials, Deconstruction Night, Laser Tag, random parties, *etc*).
- **Alumni Relations** - In the past the Department had a newsletter that was sent out to alumni roughly every semester. This project is now inactive. We have occasionally brought alumni back to give presentations to our physics majors, but this is not a regular feature of our seminar series.
- **Physics Education Research** - The Department has a considerable experience with the knowledge gained from PER. We use inquiry-based techniques in all introductory courses and in some upper level ones. We require all physics majors to complete a major research project and present their results as part of our Senior Seminar. The results of this work has been presented at AAPT meetings and published in peer-reviewed journals. We have also received two NSF ILI grants to support curriculum innovation during the 1990's.

We discuss now two additional enterprises that we believe are important for our future and to continue the upward trajectory of the Department. These items are not part of the AAPT report.

- **Web Presence** - We recognize the importance of an inviting and useful Department website to attract prospective students and as a resource for our current students. In the last 1-1/2 years content has been added to achieve these goals including a wide range of career information, a frequently-updated 'Breaking News' section describing social and academic news, detailed research pages with descriptions of the research programs, student research and publications, and Department resources. However, faculty pages are in some cases non-existent or moribund. We recognize the need to have a more active web presence and some faculty have begun to maintain blogs as way to make better use of the web. Unfortunately, the University has changed its webpage system again and considerable content has been lost and will require additional work to make it available again.

- **Outreach** - We have known for some time that one of our challenges is that few students come to the University of Richmond to study physics. The number of students who express an interest in physics on their applications is about 3-7 each year. We believe we have been very efficient in finding and recruiting students at Richmond, but the only way to solve the 'pipeline' problem is to cast our net far beyond campus. We currently hold the Physics Olympics which brings 50-60 high school students to campus, but has not been a vehicle for attracting new applicants (it works well an an on-campus recruiting event for students that are already in our introductory physics courses). We are now having discussions about how to go about attracting high school students interested in physics. Rebuilding the webpage is part of that effort.

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.