Making and Sustaining Changes in Undergraduate Physics Programs at Research Universities

Edited by Ruth H. Howes and Robert C. Hilborn

With support from:
National Science Foundation
American Association of Physics Teachers
American Institute of Physics
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A Report on the Eastern Regional SPIN-UP Workshop at Rutgers, June 4-6, 2010

Ruth Howes, SPIN-UP Regional Workshops Project Director

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Dear Colleagues,

We are pleased to provide you, with support from the National Science Foundation, a copy of the report on “Making and Sustaining Changes in Undergraduate Physics Programs at Research Universities,” based on the proceedings of the Strategic Programs for Innovation in Undergraduate Physics (SPIN-UP) workshop held at Rutgers University, June 4-6, 2010.

The case studies of the 17 participating research-intensive physics departments show that a wide variety of innovations and changes in undergraduate physics programs can lead to substantial increases in the number of undergraduate physics majors and to enhanced support from the university for the department’s programs.

We trust that you will find this report both useful and inspiring and we hope that many departments will continue to work to enhance their undergraduate physics programs.

Sincerely,

Beth A. Cunningham
Executive Officer, American Association of Physics Teachers

Kate P. Kirby
Executive Officer, American Physical Society

H. Frederick Dylla
Executive Director and CEO, American Institute of Physics

Making and Sustaining Changes in Undergraduate Physics Programs at Research Universities

A Report on the Eastern Regional SPIN-UP Workshop at Rutgers, June 4-6, 2010

As part of a project funded by the National Science Foundation, the American Association of Physics Teachers has been organizing a series of regional workshops focused on undergraduate physics programs. Three of the workshops were designed to assist physics departments in developing plans to enhance their undergraduate programs based on the findings of the Strategic Programs for Innovation in Undergraduate Physics (SPIN-UP) report.

The fourth of those workshops, the Eastern Regional SPIN-UP workshop, focused on the current state of undergraduate physics programs in research-intensive departments. Attendance at the fourth workshop was by invitation only, and all invited departments have PhD programs in physics and were known for the excellence of their research efforts. Each department attending the workshop made a presentation on its undergraduate program. Three departments—the University of Colorado, MIT, and Rutgers University—served as case study departments and described their thriving undergraduate programs.

All the departments attending the workshop either had made or were in the process of making changes in their undergraduate physics programs. Almost all of them have seen growth in the numbers of physics majors they graduate each year. Altogether, the 17 departments attending the workshop have graduated an average of 637 physics majors in each of the last five years, more than 10% of all physics bachelor's recipients.

Although each department operates in a unique environment, there was surprising consensus on some major trends in undergraduate physics and the types of changes departments had implemented. There was also agreement on major challenges facing undergraduate physics now and in the near future. This report focuses on areas of consensus and agreement. Details of the changes each department carried out are presented in the case studies that are attached to this report.

Ruth Howes, SPIN-UP Regional Workshops Project Director

Robert C. Hilborn, SPIN-UP Regional Workshops Principal Investigator

Changes Made by Many Departments

The SPIN-UP team at the conference was pleasantly surprised by the tone of the discussion which was radically different from that of discussions during the original SPIN-UP project about 10 years ago. At that time changing the undergraduate program in physics was generally considered a daring idea. Today, departments assume that they will need to update their undergraduate programs continuously and participants were eager to discuss ways to make and sustain changes. Participants discussed new teaching methods and curricula as well as methods used to demonstrate that innovations do or do not work. Most departments were constructively frank in discussing innovations they had tried that simply did not work. This information is particularly valuable to others considering making changes. The departments increasingly recognize that teaching along with research is a necessary and important part of their role. As one participant put it, "Excellence is excellence—in teaching and in research."

1. Active learning techniques, integration of technology tools, and other issues in introductory physics

Almost all departments have introduced active learning techniques into their introductory courses, and in several cases, these techniques have spread into the upper division courses. This action was motivated by evidence that lectures simply don't work in developing a functional knowledge of physics. (By "functional knowledge," we mean a deep conceptual understanding and the ability to apply the physics knowledge to new situations.) In passive lectures, students skip more classes than faculty like, and these passive lectures produce unacceptably high failure rates. In some cases, departments were familiar with Physics Education Research (PER) results demonstrating that traditional lectures are an ineffective method for increasing student learning, but their own experiences with the failure of traditional lectures in developing deep student learning provided the primary motivation for making change. Introduction of interactive teaching methods has required enhanced training of TAs, and several departments are using undergraduates in instructional roles.

For example, the Physics Department at the University of Colorado/Boulder has introduced a Learning Assistant Model in which undergraduates are trained to assist their peers in learning physics. The department has introduced active learning methods including the University of Washington Tutorials, Concept Tests, and pre- and post-testing to determine the effectiveness of innovations into all freshman physics courses, most sophomore courses, and about half of the junior and senior courses. The Physics Department has led the university in adopting "clickers" (electronic personal response systems) for very large sections so that today, 80% of the students at the University of Colorado own clickers, which are used in more than 150 courses in 20 departments. The Colorado department has made its methods widely available to the wider physics community, and they are used by many departments. For example, the Physics Department at Cornell has adopted the Learning Assistant Model.

As another example, MIT now offers its large introductory physics courses in the Technology-Enhanced Active Learning (TEAL) format: a merger of presentations, tutorials, and hands-on laboratory experience into a technologically and collaboratively rich environment. This environment is designed to promote active learning, to develop collaborative learning, to reduce the gender performance gap, and to develop new teaching and learning resources.

One universal issue that departments confront is the variety in the math and science preparation of their entering students. Many of the departments have taken active measures to help students who are less well-prepared become successful physics majors. This spread of preparation is an issue both in service courses and in introductory courses for majors.

Efforts to deal with this diverse preparation have led to a variety of solutions. Rutgers now teaches seven distinct introductory courses. Some institutions have introduced "rescue" courses. For example, the University of Michigan has introduced a new course for students who are not prepared to pass the introductory physics course. This new course is designed to provide practice in physics and to build fluency in using mathematics to solve problems. Although TEAL has improved pass rates, MIT offers a "Second Chance" option for students with a D (not a passing grade freshman year) in first semester mechanics. In this option students take an intensive three-week review in January and then retake the final exam with a chance to raise their grade to a C. The department also offers mechanics in the spring and E&M in the fall for those students who fail the first time. The "off-semester sequence" provides weekly tests and lots of tutoring. Rutgers University has introduced two full-year courses designed specifically for at-risk students and taught by dedicated staff members, one for Engineering freshmen who don't place into calculus, and the other for self-selected at-risk Arts and Sciences students

Another common approach for helping freshmen succeed in physics is to provide extra study sessions. Cornell has introduced a well-attended study session the night before homework is due, and Yale offers evening help sessions for homework and lab classes. Stanford hosts a Physics Tutoring Center that is staffed by graduate TAs and is open late afternoons and evenings.

Most departments believe that it is important that all students interested in majoring in physics have the opportunity to enroll in a physics course during the first semester of their first year. Getting under-prepared students ready to major in physics, however, can be difficult even if the students show aptitude, intelligence, and interest because they often cannot start physics in their freshman year and drift into other fields. In some cases the under-prepared students are unable to complete a physics major within four years. Physics departments have adopted a variety of strategies to deal with this problem. For example, Purdue has made calculus a co-requisite for introductory physics so almost all students can start physics immediately in their freshman years. The University of Chicago has modified its curriculum but kept as a major goal that a student should be able to start physics in the sophomore year and graduate on time. The department has introduced an early math methods course to be sure that students are prepared for the second year of physics courses. Princeton University has revitalized its sophomore mechanics course for those students who did not take the honors freshman sequence to make it different from rather than "easier" than the course taken by those who did take the honors sequence. The change has resulted in more physics majors coming from this revised general calculus-based sequence. The University of Illinois at Urbana-Champaign provides online competency exams in mathematics that all freshmen must take to help them start mathematics at an appropriate level.

Many of the research-intensive physics departments introduce research areas, new research results and research techniques as early as possible in the students' physics careers. The large research-oriented physics departments at the workshop have deployed their considerable resources to provide contemporary physics topics for their first-year majors. Methods include direct inclusion of new content in the introductory course, special courses to introduce first-year students to research in the physics department, and scholarships to support first-year students who work in a research lab.

For example, Michigan State has introduced a new lab course for first-year students. The lab course meets six hours per week in sections of six to eight students, and students can conduct non-cookbook labs in vacuum physics and optics with extensive faculty involvement.

The University of Toledo has introduced a freshman course "Frontiers in Physics and Astronomy" that is team-taught by a physicist and an astronomer to motivate students about the excitement of physics and to introduce them to the department, to the advisors and to career opportunities in physics. All students in the course must do a semester-long project, with both written and oral reports to build professional skills.

The University of Chicago now teaches quantum mechanics earlier in the major to allow students to understand topics in current physics early in their careers.

2. Flexibility in the undergraduate physics major

A second change that most departments have made is to increase the flexibility of the physics major program so that it better serves the career interests of the students in the program. In part, this change explicitly recognizes that only about a third of the recipients of bachelor's degrees in physics will pursue graduate studies in physics. The other 2/3 will attend graduate school in other areas, enroll in professional schools (medicine or law, for example), or seek employment immediately after graduation. In part, this range of careers reflects the growing importance of interdisciplinary research. It also is a manifestation of the diverse interests of very bright and hard-working students who often want to study physics along with another discipline. One unexpected side effect of the new flexibility has been the development of specialized upper-division courses for undergraduates on topics of current interest.

For example, at the University of Michigan, a flexible curriculum backed by individual advising allows students and their advisors to create an individually tailored plan for an interdisciplinary major. At Cornell, a flexible curriculum features streams that are tailored to the post-graduation plans of majors, and the department tracks graduates to be sure the physics major is serving their needs. The University of Illinois introduced a flexible curriculum with a physics core of six advanced courses plus other courses that students can choose to meet their individual goals, including courses taken in other departments.

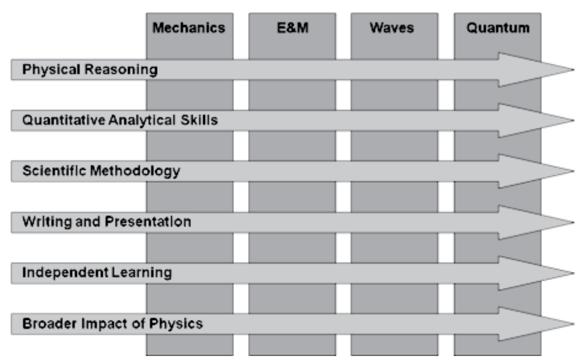
At Purdue, the upper-division curriculum was updated so that the first two years of all five major programs are the same. All the programs include two courses in mathematical physics to prepare students for more challenging junior-year work and to provide a flexible curriculum to meet students' varied goals, including the opportunity to take specialty courses in both physics and other disciplines. These changes allowed the department to add many dual-level (graduate-undergraduate) specialty courses. Physics faculty have adapted the requirements for the applied physics program to make it easier for students to have a second major in fields such as mechanical engineering. Rutgers offers several options for the physics major that cater to the needs of students with differing post-graduation goals.

This new flexibility requires agreement from a majority of the faculty. Since some of the new options require students to take courses outside the physics department, it can be difficult to convince conservative colleagues that this flexibility is a good idea. It also requires collaboration with faculty colleagues in other departments, a growing trend as physics departments grapple with the increased focus on interdisciplinary training and research and in changes in the expectations of life sciences departments for what their majors need to learn about physics.

Departments have taken a variety of steps to involve nearly all faculty members in enhancing their undergraduate programs. Cornell and Illinois introduce new faculty members to active learning methods used in introductory courses by involving them as part of a team with experienced faculty members. Michigan holds regular faculty meetings over the summer to discuss changes in courses for the following year. Penn State and Chicago have formed active faculty committees to discuss teaching and curriculum in undergraduate courses. Physics faculty members at Stanford have worked with the School of Engineering to introduce an Engineering Physics major. The number of students pursuing a master's degrees in engineering while completing an undergraduate major in physics is increasing. Harvard has taken steps, including polling faculty on skills that they believe physics majors should acquire, so that has all faculty members have input into the process of change.

Introducing flexibility has led departments to identify explicitly the skills that a graduating physics major should have. The departments at the workshop are in the process of identifying both technical skills such as computational modeling and statistics for error analysis and "soft" skills such as working effectively on a team or writing clearly that their students should acquire as undergraduates. Many participants at the workshop feel that, in the long run, the skills students acquire, including the ability to solve physics problems from first principles, are more important than the specific physics content they know. Departments face difficult decisions on whether to spend limited time teaching content or skills and debate how to be sure that their students master both.

For example, Harvard has identified a set of skills that students should acquire during their first two years of physics. These skills constitute what they call the "horizontal curriculum" as shown in the figure. The department is currently discussing assigning to each cohort of students a faculty member whose teaching responsibility would be to ensure that this cohort of students masters the horizontal curriculum as well as completing the standard physics courses.



There is a growing concern in these large research-oriented departments about the small number of students preparing to be secondary-school physics teachers. In part, this concern arises from enlightened self-interest in securing a supply of well-prepared students and in establishing a network of high school teachers who will send their best students to the university. However, there is also a genuine concern for the education of the future leaders of the nation and the future health of physics as a profession.

At Rutgers, the physics department has a long-established collaboration with the Graduate School of Education which has been very successful in graduating well-prepared physics teachers at the rate of six to eight each year. Innovations produced by this collaboration have been very successful in increasing the retention of students who are under-represented minorities.

The physics departments at the University of Colorado/Boulder and Cornell are part of the Physics Teacher Education Coalition (PhysTEC – a project of APS and AAPT with financial support from NSF) and have implemented concrete strategies to increase the number of and improve the preparation of secondary physics teachers.

3. Engaging students in undergraduate research

All the participating departments pride themselves on providing undergraduate students with meaningful research experiences. These experiences overcome the anonymity of large departments and provide undergraduates with a set of mentors including faculty members, postdocs, and graduate students. Faculty members offer a large selection of research projects from which students can choose and thus can offer them a broader experience of physics than they see in their courses alone. Involving undergraduates in research allows departments to identify talented and energetic students. It is a recruiting tool for departments, particularly if they can offer scholarships to talented first-year students who are involved in a research project. Later on, research stipends are a way of providing money to talented students in need of additional financial resources.

To promote undergraduate participation in research, Purdue University uses its Ascarelli Fellowships to support undergraduate research beginning in the students' first year. The fellowships often lead to longer-term research projects and are a useful tool for attracting talented students to the study of physics. The University of Illinois at Urbana/Champaign offers a formal three-semester sequence of integrated research and instruction with the goal of preparing a senior thesis and developing skills in modern scientific communication. Georgia Institute of Technology has reorganized the schedule for its physics majors to introduce undergraduate research earlier. Over half the declared physics majors at Stanford University pursue research on campus during the summer. The university provides a stipend of $5600 for each student in the 10-week program. Cornell University has introduced a course, "Data Analysis in Particle Physics," which gives freshman and sophomore students tools to analyze experimental high energy physics data. The instructor helps students who complete the course find research positions where they can use their skills.

At Princeton, all undergraduate majors are involved in research. The department requires three independent projects for all majors: two junior papers plus a senior thesis, each with an individual faculty advisor. The independent work requirement puts faculty into contact with undergraduates in a research environment and integrates the teaching and research sides of the department. Faculty experience with undergraduates leads to faculty interest in hiring undergrads so that about 30 students work in the department each summer. These work opportunities become a recruiting tool for potential majors.

4. The role of laboratories

One problematic area where several departments have already made dramatic changes is in the introductory, intermediate, and advanced labs. In the introductory course, departments are grappling with ways to improve student learning of physics concepts by using lab time for such activities as the University of Washington Tutorials. Introductory labs are also being used to teach techniques such as computational modeling (notably in the Matter and Interactions curriculum at Purdue and Georgia Tech, which uses VPython), and to provide students with authentic experiences in conducting physics experiments. A current concern for many departments is how to introduce more life science examples into the introductory physics courses for students in the life sciences. Advanced labs are used not only to introduce students to current experimental techniques and data analysis, but also to teach them such physics professional skills as writing papers and proposals. Some departments even include ethics training in these labs.

While there is consensus that labs are important for preparing students both for immediate employment and for graduate school, there is a variety of opinions on the best way to organize laboratory work. Most of the participating departments agree that both introductory and advanced labs consume a disproportionate share of faculty time and departmental resources.

The University of Virginia focuses on two introductory and two intermediate labs which are taught with eight students per section to bring the students into close contact with faculty and introduce them to state-of-the-art research techniques. The labs produce excellent learning for students, but they are very expensive in terms of faculty time as well as equipment.

At the University of Illinois, the department has introduced a modern experimental physics lab with three cycles—

Nuclear & Particle; Atomic, Molecular & Optical; and Condensed Matter—all of which are taught by content expert faculty, use networked digital scopes and electronic logbooks, and stress modern data analysis techniques.

As part of its response to new ideas from the life sciences in how students should be trained (see Future Challenges, section 5, in what follows), Yale University has reworked the introductory physics course for life science majors to make it more relevant to students and to the expectations of the life science community. In particular, the labs for this course have been reworked to use examples that are important in the life sciences, and students are tested in practical exams with new emphasis on teamwork

5. Building community

Large departments have increased their efforts to build community among their students. Efforts include improvements in advising and providing better career information. Some departments boast of their active Society of Physics Students (SPS) chapters. Others have taken steps to get to know their students and gain feedback from them. In the environment of a large research university, it is easy for undergraduates to get lost, and efforts to link faculty and students pay dividends in undergraduate satisfaction and in the numbers of majors.

Rutgers supports a very active SPS chapter that sponsors monthly speakers with free pizza and sodas, holds GRE study sessions, runs field trips, and hosts two barbecues for the whole department every year. The department assigns a single adviser for all majors to ensure that they receive consistent advice and to avoid disruptions in advice because of sabbaticals. The adviser gets to know all majors very well. The department also recruits heavily those students who have been accepted at Rutgers and who have expressed an interest in physics. These efforts have paid off in an increasing number of physics majors graduating from the department (32 in 2005 and 45 in 2010).

At Cornell, all faculty are involved in freshman advising, and a rotating set of 10-20 faculty members advise upper division students. The department finds it valuable to have all faculty engaged in mentoring undergraduate students. The physics department actively seeks students' input to the department using online surveys, anonymous drop boxes, and various student-centered events. Students are encouraged to assume responsibilities in all aspects of the department: research, mentoring/recruiting newer students, teaching, and outreach.

The University of Chicago physics department seeks feedback from its students in spring freshman interviews and by holding town meetings with undergraduates to get feedback from them. At Penn State, physics majors now have one "point of contact" for all undergraduate advising with a person who is also the SPS, Study Abroad and CoOP advisor. (CoOP is a program in which students complete four or five work terms with the same employer, are paid for their work, and receive credit on their transcripts for their experience). The advisor also teaches the freshman seminar and junior career advising course.

Several departments have improved the way they provide career advice to their majors. Penn State changed the junior "research" course into a required two-credit course in the spring of the junior year, featuring outside speakers as well as faculty members, career advice, and preparation for the General Graduate Record Exam, Praxis, and Major Field Tests. The students are also provided with a collection of career information. The University of Chicago now includes a discussion of career goals in its annual graduate school forum for its undergraduate majors.

Community is particularly important in recruiting women and minority students as majors in physics. The percentage of women physics majors hovers near 20% nationally and has remained there for several years. It is encouraging that four of these large departments (Stanford, Harvard, the University of Toledo, and Cornell) currently have women chairs. Several other departments have taken active steps to create a woman- and family-friendly environment, but women continue to be severely underrepresented in physics. The departments have been less successful in recruiting African-American and Hispanic-American physics majors and helping them succeed.

As part of the workshop, Anthony Johnson of the University of Maryland, Baltimore County provided the group with his own story that clearly illustrated the importance of providing role models to students from underrepresented groups and of welcoming these students into research groups and helping them feel at home. MIT boasts that 33% of its physics graduates are women. With the help of a team from APS, the physics department at Cornell recently held a Gender Equity Conversation with faculty, students and staff. Not only did this conversation suggest changes to address the gender imbalance, but it provided feedback on gender-neutral issues such as campus safety. Michigan State University has been successful in recruiting female faculty members. There are now 10 female faculty members in the department, up from two in 2001-02. The University of Toledo has established chapters of The Initiative for Diversity in Education and Leadership (IDEAL) Scholars Fund, American Women in Science (AWIS) and Women in Science and Engineering (WISE) on campus to promote diversity in physics and other sciences.

6. Sustaining change

Once departments revise their undergraduate physics programs, they face the challenge of sustaining these changes and of keeping revised courses fresh and current. They must also collect data that shows that the new curriculum works both in attracting students and in improving student learning. The key to sustaining improvement is to secure the support of a majority of faculty in a department. Some of the departments have established PER groups to carry out research in physics education, to help maintain the quality of their courses, and to provide evidence that revisions are successful. Others have forged collaborations with other departments within their universities.

The University of Illinois began to introduce new teaching and learning methods into its introductory course more than 10 years ago and continues to do so. A series of department heads provided strong support with released time to develop and implement changes. The department also created a new Associate Head position to oversee and continually improve undergraduate education. The department established an infrastructure to sustain changes and bring new faculty members on board with interactive teaching methods. Perhaps the most important contribution in sustaining change is the department's culture: courses belong to the department ("our course") not to individual faculty members ("my course"). Finally, a Physics Education Research (PER) group has been created that serves as a source of continual change and new ideas and pedagogical methods as well as a resource for carrying out research to evaluate the effectiveness of the changes in increasing students' learning.

The University of Colorado introduces new faculty members to enhanced pedagogy with veteran/apprentice team-teaching and shares teaching materials among members of the department. Georgia Institute of Technology has hired several non-tenure track faculty members to play leading roles in their enhanced introductory course, and Stanford has hired a specialist in PER to suggest changes, to oversee their implementation, and to evaluate their effectiveness. The Stanford department invited four nationally recognized PER researchers to introduce the faculty to the new methods and why using them is important. The Princeton physics department established a permanent "recruiting czar" to be shadow advisor, watch admissions, and be sure that majors are recruited from the general calculus-based physics sequence.

Summary of Changes

Like politics, all changes in undergraduate physics programs are ultimately local: that is, unique to the department making them. There is no "one-size fits all" program. However, these very successful research-oriented departments have all adopted the use of active learning techniques, more flexibility in their curricula, involvement of undergraduates in research, revision of their introductory and advanced labs, and the development of a sense of community among students. They have also developed ways to sustain the changes they have made. These changes have been successful at least in increasing the numbers of students graduating with bachelor's degrees in physics, a statistic that serves as a proxy for other measures of a thriving undergraduate program. It is encouraging that several large departments have demonstrated a scholarly and systematic approach to change and have collected data to indicate that their changes work. This kind of systematic reform involves many people in a department and offers support to those making the changes.

Future Challenges

1. Diversifying physics programs

In spite of the efforts of some physics departments, recruiting and retaining physics majors who are women and minorities remains a largely unfulfilled goal. Jim Stith, Vice President Emeritus of AIP, who is himself African-American, says that "I've been lonely everywhere I have worked." And Anthony Johnson of the University of Maryland, Baltimore County, who was speaking about the role of undergraduates in his research group, demonstrated what a difference one group leader who actively recruits minority students can make. All participants agreed that this is an issue that physics as a community must address in the near future. Women already represent almost 50% of the students taking physics in high school (American Institute of Physics Statistical Research Division). More than 50% of college students are women, and Hispanics and African-Americans are a rapidly increasing segment of the college-age population. Physics cannot afford to ignore this large talent pool.

Unfortunately, there were few suggestions of specific steps that departments might take to increase their diversity. One idea is that both faculty and teaching assistants be required to take the Implicit Association Test to identify their hidden preconceptions about groups of people. A second idea is to provide scholarship aid targeted towards minority students. One easy step that all programs could take is to identify resources that help students understand the department's programs and make those resources available to all students. For example, place copies of old exams and labs in the reserve room of the library or the student study room. Too often, majority students have these resources available in their study groups. Because many students from underrepresented groups tend not to participate in these study groups, they often miss out on these assets. Clearly the issue of broadening participation in physics is one that both the physics community and the funding agencies ought to address immediately.

2. Sustaining change in and emphasis on undergraduate physics programs

Although all departments at the workshop have implemented changes in their undergraduate programs and these changes appear to be successful, sustaining and building on these efforts is a key challenge for most if not all physics departments. Many of these changes were spearheaded by a single enthusiastic faculty member, and while other members of the department are pleased to have lots of excited physics majors, many are content to do their research and let the enthusiast or two "take care of" undergraduate education. The problem is worse among a few very traditional physicists (both young and old) who say, "I learned physics from lectures and text books. If these students don't want to work hard and learn math in high school, they can't expect to be physics majors. This PER is not science but a set of opinions, and no one with any sense pays attention to it." No amount of data seems capable of convincing these faculty members of the usefulness of active learning methods and revised curricula. Departments will be challenged to find ways to engage such faculty members in enhancing the undergraduate program or at least reducing the opposition that such faculty members often exhibit to change.

Because reforms in many departments rely on a single key person often, with the support of a far-seeing chair, the loss of that person or a change of chair can slow or even reverse the progress that the undergraduate physics program has made so far. This problem is exacerbated because many departments have used faculty members who are not on tenure lines to spearhead reforms. These faculty members, who are generally excellent physicists and excited about reform, are vulnerable to budget cuts and to shifts in departmental and university approaches to the undergraduate program. Perhaps funding agencies and universities should consider targeting funding programs towards reform of undergraduate education in such a way that these non-tenure-line faculty members are encouraged to be PIs for external grants. Such external support allow the non-tenure-line faculty to contribute more directly to the long-term develop of the departments programs.

3. Career opportunities for holders of terminal bachelor's degrees in physics

What kinds of careers do people with physics degrees pursue? Unlike chemists and engineers, there are almost no jobs labeled "physicist" in industry for physics bachelor's graduates. As a result, physics graduates take a jobs with a wide variety of titles. Human Resources Departments generally specify the degrees they wish applicants to hold and often do not include physics in the list. Parents, particularly those of first-generation students, all too often ask advisors what their son or daughter can do with a degree in physics and they may even refuse to allow their child to major in physics because of the perceived lack of career opportunities. Clearly, the physics community faces a huge public relations problem in selling our undergraduate programs and the careers that students can pursue with those degrees.

AIP, APS, and AAPT have made a sincere effort to put good career information into the hands of physics advisors. The AIP website on Careers is an excellent resource for those needing this kind of information. Departments have developed seminars, colloquia, and even special courses to inform their students about varied opportunities open to them. In some cases, they have called upon alumni to help with these efforts. As a community, physics must sustain and expand these efforts. We also need to convince the public that a graduate with a bachelor's degree in physics is at least as good a thinker and communicator as a graduate with an undergraduate degree in history, English or psychology.

There are two areas where efforts to promote physics bachelors holders are proving more successful. First the societies' efforts to expand the preparation of qualified secondary physics teachers (PhysTEC) has expanded the number of well-prepared high school physics teachers, and these students are finding jobs. A second success story has been selling physics as a strong preparation for professional schools, particularly medical school, law school and business school.

Physics students have excellent track records in these areas, and departments can make strong cases, based on the careers of their own alumni, that physics is the major that prepares you for admission to the competitive schools and helps you get into them. The flexible majors are a plus here since they allow students seeking these careers to take appropriate courses in addition to physics.

4. Maximizing the effectiveness of labs

Almost all departments represented at the workshop had made considerable effort to make their introductory and advanced laboratories more effective both in helping students acquire the skills they need to become professional physicists and in introducing them to the excitement of new techniques and ideas in physics. But these efforts require considerable financial and personnel resources. There does not seem to be a magic solution to this resource problem, although there are a number of good ideas and successful models. Nevertheless, the models all appear to demand resources that are difficult to come by, and labs continue to be a challenge to all departments.

5. Changes in engineering and the health sciences

Physics departments typically have small numbers of majors compared to most other science and engineering departments. They also teach heavy service loads, primarily to students majoring in the life sciences or in engineering. Because huge service loads are one key to maintaining office and research laboratory space and faculty lines, physics departments may be challenged by changes in the way life science and engineering students are educated.

The Association of Medical Colleges and the Howard Hughes Institute recently completed a report recommending changes in the basic science preparation for future MDs, both as undergraduates and in medical school. Just as ABET 2000 shifted engineering requirements to a competency-based system, so this report calls for a shift to competency-based preparation of premed students and medical school students. This new emphasis will be reflected in the current redesign of the MCAT examination, the new version of which will be available in 2015. These recommendations and changes have prompted several departments to rethink physics courses required for degrees in the life sciences by reducing the emphasis on Newtonian mechanics of particles, by including more thermal physics, statistical mechanics and fluid dynamics, and by introducing new examples from the life sciences in lecture and labs. The situation is still in flux, but the large service loads taught by most physics departments will demand their attention to these changes.

Although most physics departments have already responded to the changes in ABET requirements, maintaining a constructive relationship with engineering departments demands that physics departments pay attention to introducing elements of active learning and design in the calculus-based physics courses taken by future engineers.

6. Resources in a challenging economy

Like nearly all departments, physics departments are operating in a climate of very limited resources. Effects include declining numbers of faculty lines, reduction in the numbers of TAs, and declining budgets for new equipment. The situation arises from the current economic downturn, which has hurt endowments, state funding for universities, and even donations to universities. While it is beyond the scope of this report to suggest fixes for these economic problems, they are a significant challenge to the efforts to increase the effectiveness of undergraduate physics programs. Physics departments will need to be creative in finding ways to do better with fewer resources.

Conclusion

The SPIN-UP Regional workshop at Rutgers focused on undergraduate programs in research-oriented physics departments. These departments are important to physics as a profession because they produce a large fraction of the total number of physics majors. These departments have devoted much time and many resources to improving their undergraduate programs. Their efforts have succeeded in increasing both the numbers of physics majors graduating each year and the effectiveness of instruction for students in their service courses. Nevertheless, the workshop participants outlined a number of challenges that undergraduate programs in these departments generally face. The physics community has come a long way in improving its undergraduate programs since the mid 1990s. By collectively identifying the challenges facing undergraduate physics and learning from the successes within the physics community, we can meet those challenges and build a vibrant and productive future for undergraduate physics.

Appendix A

The Eastern SPIN-UP Regional Workshop: Rutgers University, June 4-6, 2010

Participants arrive **Friday, June 4,** late afternoon

4:00 pm	Registration – set up posters
5:00 pm	Welcoming Remarks – Bob Hilborn, SPIN-UP PI, and Rutgers representative
5:15 – 5:45	Carl Wieman, "Transforming the departmental culture to improve student learning (and other miracles)" Due to confirmation process and schedule changes, Dr. Wieman was unable to attend and was replaced by Bob Hilborn
5:45- 6:00 pm	Questions and Discussion
6:00 pm	Brief Reports I – twenty minutes per institution – files pre-loaded – 3 reports per session Chicago, Cornell, Georgia Tech
7:00 pm	Reception with posters
7:30 pm	Dinner
8:30 pm	Brief Reports II Harvard, Illinois, Michigan

Saturday, June 5

8:00 am	Breakfast
8:30 am	Case Study 1: MIT
9:00 am	Case Study 2: Rutgers
9:30 am	Break
10:00 am	Diversity and Undergraduate Physics in the 21st Century – Jim Stith
10:45 am	Case Study 3: University of Colorado - Boulder
11:15 am	Brief Reports III Michigan State, Penn State, Princeton
12:15 pm	Lunch
1:00 pm	Breakout session – new directions in the undergraduate physics curriculum, tracks, interdisciplinary work, etc.
2:00 pm	"The role of Physics Education Research in introductory course reform and physics teacher preparation" – Eugenia Etkina
2:45 pm	Break
3:30 pm	Breakout session – introductory physics – serving engineering, life sciences

4:30 pm	Brief Reports IV Purdue, Stanford, Toledo
5:30 pm	Free time
6:00 pm	Informal Reception
6:30 pm	Dinner
7:30 pm	"Undergraduate Research – The Start of a Career," Anthony Johnson, University of Maryland, Baltimore County
8:30 pm	Informal Reception

Sunday, June 6

8:00 am	Breakfast
8:45 am	Breakout session – what do our students do after graduation, do our programs prepare them for what they actually do?
9:30 am	Brief Reports V
	Virginia, Yale
10:15 am	Break
10:30 am	Defining the key challenges facing undergraduate physics over the next ten years, What needs to be done
11:15 am	Wrap Up and Evaluation – Bob Hilborn and Karen Johnston
12:00	Lunch and adjourn

Appendix B

PARTICIPANTS IN SPIN-UP RUTGERS WORKSHOP, JUNE 4-6, 2010

The SPIN-UP Team

Jim Stith, Vice President Emeritus, American Institute of Physics

Bob Hilborn, Head, Science/Mathematics Education, University of Texas at Dallas

Ruth Howes, Professor Emerita, Ball State University

Karen Johnston, CEO Momentum Group, Fort Worth, Texas

Jack Hehn, Director of Education, American Institute of Physics

Ken Krane, Professor Emeritus, Oregon State University

Anthony Johnson, Director, Center for Advanced Studies in Photonics Research (**CASPR**), University of Maryland, Baltimore County

University of Chicago

Stuart Gazes

University of Colorado at Boulder

Noah Finkelstein
Michael Dubson
Kathy Perkins

Cornell University

Erich Mueller
Matthias Liepe

Georgia Institute of Technology

Danny Caballero

Harvard University

Logan McCarty

University of Illinois at Urbana-Champaign

Gary Gladding

University of Michigan at Ann Arbor

Brad Orr
Tim McKay
Gus Evrard
James Liu

Michigan State University

Gary Westfall

Massachusetts Institute of Technology

Peter Dourmashkin
Tom Greytak

Pennsylvania State University

Richard Robinett

Princeton University

Peter Meyers
Lyman Page

Purdue University

Hisao Nakanishi
Andrew Hirsch

Rutgers University

Mohan Kalelkar, Local Chair
Eugenia Etkina
Emil Yuzbashyan

Stanford University

Patricia Burchat
Sarah Church
Chaya Nanavati

University of Toledo

Karen Bjorkman
Jacques Amar
S. Thomas Megeath

University of Virginia

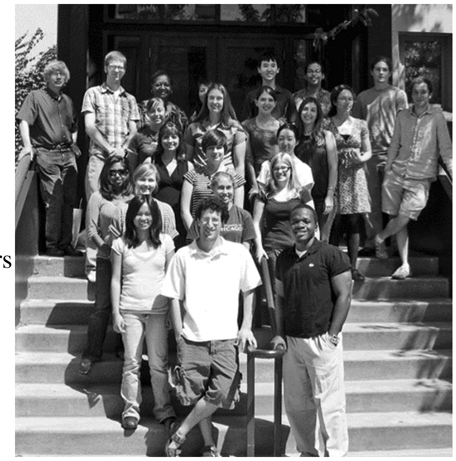
Blaine Norum
Stefan Brassler

Yale University

John Harris
Sidney Cahn

Appendix C: Case Studies

Case Study: University of Chicago



REU students, summer 2009.

Department description

– 33 tenure-line faculty members plus two senior lecturers who act as advisors
– 140 majors currently enrolled from sophomore to senior year
– Over the last five years, graduated an average of 37 majors per year
– 450 students taught per quarter in a variety of courses, including both an honors freshman sequence for well-prepared students and a regular and larger calculus-based physics sequence
– Offer a BA in Physics, an honors BA in Physics and a BA in Physics with a specialization in astrophysics, plus a minor in physics

Changes

– Teach quantum mechanics earlier as the basis of current physics.
– Introduce an early math methods course to prepare students in the non-honors freshman sequence for the sophomore curriculum when they are combined with students who have taken the honors sequence.
– Introduce a more flexible curriculum with three electives. All changes were subject to the constraint that a student declaring a physics major in the sophomore year should be able to graduate in three years without heroic efforts.
– Hold an annual forum on graduate school admission and conduct a special seminar, Physics 990, to prepare students for the GRE.
– Seek feedback from its students by holding town meetings with undergraduates to get feedback from them.

Evidence of success

– In 1995-2000, the department graduated 18 majors per year on average. From 2005 to 2010, the average number of physics majors graduating was 37.
– The number of electives has increased since the curriculum changes were implemented and reflects both student and faculty interests.
– More than a third of the physics majors who graduate with degrees in physics now enter the program from the regular calculus-based course with the aid of a new math course to prepare them for sophomore courses.
– Nearly all students participate in undergraduate research although it is not required and the department has earned three Apker Awards since 1992.

Steps to sustain change

• Periodically introduce new electives while pruning those that have not been popular in order to sustain the flexibility of the physics program.
• To sustain the success of the "early" math methods course for non-honors students: assign a physics grad student as TA; meet with the appropriate Math instructor before the start of the quarter to discuss the history of the course and to articulate its aims within the physics program; Undergraduate Program Chair meets occasionally with the instructor during the quarter to monitor progress and perhaps adjust expectations.
• The department has a standing Teaching Activities Committee which intervenes if one course is not fulfilling its role in the curriculum (i.e. a required course being taught like a special topics class).
• Supported the efforts of undergraduates to establish a Society of Women in Physics chapter this year.

Issues

– The department is concerned that its production of women majors is only 20%, at the national average, but still low.
– The physics building dates to 1985 and space is at such a premium that it is difficult to establish dedicated undergraduate areas.

For more information contact: Undergraduate Program Chair, Stuart Gazes, **gazes@uchicago.edu**

Case Study: The University of Colorado at Boulder

Department description

- 52 tenure-line faculty members plus 12 full-time non-tenure line faculty members
- 304 majors currently enrolled between sophomore and senior years
- Over the last three years, graduated an average of 50 majors per year
- 2000 students taught each semester in the calculus- and algebra-based physics sequences plus other service courses
- Offer a BA in Physics and a BS in Engineering Physics

Students in the 2500-sq.-ft. Help Room in the Physics Department at the University of Colorado.

Changes

- In 1996 the introductory courses started using clickers and peer instruction, and increased the use of challenging conceptual questions on exams. By 2003, these practices had spread to most introductory instructors and currently all introductory and service courses (for majors and non-majors) are taught with concept tests and Peer Instruction, and use iClicker technology in the classroom.
- In fall 2003, CU instituted the Learning Assistant (LA) Model of instruction in which well-trained undergraduates serve as additional instructors in courses, allowing and encouraging faculty to use more interactive teaching strategies such as group-work activities. CU uses LAs in calculus-based physics with University of Washington Tutorials, in upper-division physics with UW and CU tutorials, and in non-majors courses with in-class peer discussion and homework help sessions. See: **http://stem.colorado.edu**
- In fall 2007, the department began a major effort to reform upper-division courses. The use of clickers and concept tests had been spreading to upper-division courses since 2004. In 2007, the faculty engaged in writing a cohesive set of course learning goals for upper-division E&M that have since been identified as general goals for the major (posted at **http://www.colorado.edu/sei/departments/physics.htm**). The E&M I and Quantum I courses have been reformed to include: learning goals, clicker questions, in-class white-boarding and kinesthetic activities, revised homework, and optional weekly tutorials. Resources for faculty include a compilation of common student difficulties and a conceptual assessment of learning for each course. Banks of concept questions are also available for other upper-division courses: **http://per.colorado.edu/cts/index.htm**
- Thus, all freshman courses, most sophomore courses, and half of junior and senior courses have been transformed to include research-based, interactive, and student-centered approaches. CU has a significant history of measuring the impact of these reforms, and using those measures to guide new changes. The department has almost 10 years of learning measures in the introductory course sequences, and several years in upper-division Quantum and E&M.

Other significant changes in the department:

- In 2000, established a physics help room—a dedicated large space, in which all faculty members and TAs hold office hours, so the room is always staffed. Peak use exceeds 200 students at a given time.
- In 2002, established a project and website that now has more than 85 interactive simulations for learning physics: **http://phet.colorado.edu**
- In 2003, established a physics education research (PER) group to measure success of reforms and to help instituted them.
- In 2004, joined the APS /AIP / AAPT PhysTEC project in an effort to increase the numbers of well-prepared secondary physics teachers. In 2008 joined the APLU's Science and Mathematics Teacher Imperative.

Indicators of success

- Measures indicate that student learning has increased in our transformed courses, both in introductory physics course and in upper division courses. Most reforms are very popular with both lower and upper-division students—an exception still being the Washington Tutorials in calc-based physics where the student reception is moderate and varies with the lead instructor.
- There has been widespread buy-in to the reforms among faculty and students as measured by surveys.
- Physics has been successful in obtaining external funding bringing in millions of dollars (from NSF and private foundations) for reforms.

– The efforts in the Physics Department have catalyzed change across the university. Today 80% of the students at the University of Colorado at Boulder own clickers, which are used in more than 150 courses in 20 departments.
– As mentioned above, we measure increased achievement/learning in our transformed classes. For example in measures of students' conceptual mastery, we observe learning gains two to three times the national average for non-transformed classes. Students in traditional courses learn less than 25% of the material they do not already know (Hake, *Am. J. Phys*. 1998), while students in our transformed courses learn as much as 66% (Finkelstein and Pollock, *Physical Review ST: PE*R 2005). Furthermore, two years later, student performance is maintained. In a study of students' conceptual mastery of electricity and magnetism (using the BEMA from Ding et al, *Phys Rev ST*: PER, 2006), we found that: 1) students in upper division E/M posted the same levels that they had freshman year, 2) students who had participated in transformed, interactive classes as freshman outperformed their peers who had not, in the upper division courses, and 3) those students that had served as Learning Assistants performed the highest of all groups (Pollock, *Physical Review: ST: PER*, 2009).

Steps to sustain change

- Introduction of new faculty members to reformed pedagogy with veteran/apprentice team teaching.
- Provided resources, including space, TA training, Learning Assistant Training, and support reformed courses (such as the use of the U Washington Tutorials).
- Sharing of materials for reformed teaching among members of the department.
- Through the Science Education Initiative at Colorado, we have been able to create an official archive of course materials, and instructional guides for future use.
- By engaging in a team-design of course reforms (bringing many faculty together) to establish consensus learning goals, we have a broad buy-in of faculty in these reforms.
- Through the structure of the Learning Assistant program, where students are hired to support course reforms, we ensure that there is institutional structure supporting these reforms.
- There have been several structural changes for courses:
  – We have dedicated space to run Tutorial/LA efforts in the introductory sequence.
  – In the upper division we have established co-seminars to provide credit for extra time that students are spending on Tutorials in E/M and Quantum courses.

Issues

– Even in a reformed departmental culture, there is significant variation in pedagogy. Faculty matter and their practices vary.
– Funding, as a state school, poses challenges for the demands of increased interaction and facilities for teaching our students.
– Our course sizes (at all levels) continue to increase. We are challenged to provide the resources for these courses: teaching assignments (enough faculty, TAs, LAs), and space for issuing these courses.

For more information see (or contact)

http://www.colorado.edu/physics

http://www.colorado.edu/sei/departments/physics.htm

http://per.colorado.edu/

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Case Study: Cornell University

Department description

- 43 tenure-line faculty members and one full-time non-tenured faculty member
- 75 majors in program between sophomore and senior year
- Over the last five years, graduated an average of 28 majors per year although numbers have fluctuated considerably (max=45, min=17)
- Teach about 1400 students a semester in introductory physics sequences and service courses
- Flexible curriculum features streams that prepare students for diverse careers as well as graduate school; 60% of students go on to graduate school; offers a BA in Physics as a liberal arts institution
- Students typically declare their major at the end of their sophomore year
- Strong belief in incremental and continuous change (self-paced auto-tutorial course, student response systems,…)

Department student-faculty lunch.

Changes

- Concerted effort to increase communication with students: posters, info sessions, handouts/brochures, web presence. All freshmen with expressed interest in physics receive freshman advisor from Physics. New “flowchart” of the major program and “freshman brochure” help students choose their initial physics courses, and plan their studies. Director of Undergraduate Studies meets one-on-one with all prospective majors. One-on-one debriefing of all graduating seniors. Invite students to lunch with faculty once per year. Held a Gender Equity Conversation with students. Introduced “suggestion box” near main physics office.
- Department has increased resources directed towards SPS. Strong faculty liaison helps encourage SPS to put on more events and make those events more successful. New students are encouraged to join SPS. Research, teaching, and outreach activities are advertised through SPS, making membership more valuable. Faculty members are strongly encouraged to participate in SPS events. Department provides budget for pizza and supplies, as well as help in producing posters. Encourage newly formed “Society for Women in Physics,” providing pizza.
- Encourage innovation from individual faculty by advertising their successes, and providing mechanisms for preserving their innovations. Advertisement involved production and dissemination of booklet.
- Make the importance of undergraduate research more explicit to students. Provided web resources for finding research positions. Compiled list of students working in various labs. Survey students to learn about how they are finding research positions. Use results to help guide students.
- Revamp career info session to focus less on graduate school, and more on alternative careers. Invite representatives from career services, librarian, and graduate students to participate. Heavily advertise career session.
- More aggressive recruiting from prospective freshmen and from current students. Participate in reception for “Dean’s Scholars.” Put on “Physics Days” events, where students who have been admitted to Cornell and in hands-on physics-related events. Put up posters outside major lecture theatres advertising physics options, having SPS announce their events in intro courses.
- Participation in the Physics Teacher Education Coalition (PhysTEC), a program designed to increase the production of high-school physics teachers. Under this program Cornell was able to hire a “teacher in residence” who undertook a number of initiatives aimed at promoting high school physics teaching. The department created a successful undergraduate teaching assistant program, modeled after the University of Colorado’s.
- Revamp of auto-tutorial course. Extensive use of online feedback, and online scheduling tools for that course. Focus on quality of student experience. Creation of new online mini-lectures on specific topics (ex. free-body diagrams).
- Pre-lecture slide-shows in large lecture courses to engage students, and reduce class-time spent on announcements. Intro courses for life science students incorporate a large number of powerpoint “applications” which connect the basic physics concepts to real-world examples. Instructor uses interactive pen display in some introductory classes which streamlines combining written notes and powerpoint. Allows posting of notes to web after class. Routine administration of pre-post tests (such as Force Concept Inventory) in all introductory courses.

– Experimentation with different homework systems, and with changing which introductory course contains thermodynamics.
– Increased emphasis on transferable skills in several of our introductory courses.
– Established “study halls” for students in introductory honors classes. These sessions are held the day before homework is due, and have either a TA or the instructor available.
– New introductory mechanics labs based on video capture to produce strobe diagrams.
– Implementation of web-based video Lecture-Demo catalog.

Indicators of success

– Large attendance at career info session (~100 students)
– Much less attrition in introductory honors class. Excellent participation in study halls (>50% per week), with strong signs of peer learning (same students resisted cooperative learning in recitation sessions). Interviews indicate students view physics program environment as “cooperative” rather than “competitive” environment.
– All graduating seniors reported having performed research.
– Students are seeking outreach opportunities.
– Enrollment doubled in autotutorial course after innovations were introduced.
– Through PTEC, the physics and education departments have developed closer ties.

Steps to sustain change

• Introduced centralized WIKI for course instructors to document innovations. Advertise innovations to faculty at “Monday Lunches.” Booklet on innovations. Regular discussion of undergraduate issues at Monday Lunches and faculty meetings. Every semester have one colloquium on teaching issues. Department is attempting to preserve innovations though a courses WIKI. Discuss education matters at faculty lunches. Invite physics education researchers to present colloquia.
• Large introductory courses use an apprentice system where new instructors first are involved with the course at a subordinate level.
• Undergraduate Teaching Assistant (UTA) program includes “master UTAs” who have already been a UTA once, and provide continuity to program.
• Encourage faculty teaching related courses to meet in small groups to coordinate instruction.
• Active curriculum committee.
• Attempt to make recruiting materials easy to maintain. Put information on web. Use templates for posters.

Issues

– Helping students find the right track. There is a lot of pressure to take the more difficult honors classes, which are not appropriate for everyone. Ensuring that students, faculty, and advising deans all recognize the breadth of options available to physicists, and do not discount nontraditional paths.
– Continuity and sustainability of changes.
– Coordination between different courses: both sequential courses, and parallel courses in different tracks. Coordinating the different parts of individual courses (ex. Labs and lectures). Coordinating with engineering physics program (curriculum, recruiting, etc.)
– Overcoming institutional and departmental inertia to make major structural changes
– Increasing numbers of graduating majors
– Ensuring that majors graduate with all of the appropriate skills we expect of a physicist: ability to model novel physical systems, solve real problems, communicate effectively, use computers in their modeling and problem solving.

For more information contact: physicsdus@cornell.edu

Case Study: Georgia Institute of Technology

Department description

Undergraduates picnic with graduate students.

- 36 tenure-line faculty members and five full-time non-tenure-line faculty members
- 110 majors currently enrolled between sophomore and senior year
- Over the last five years, graduated an average of 25 majors per year
- 2300 students per semester taught in the physics sequences and other service courses
- Offers a BS in Physics, and a BS in Applied Physics

Changes

- The sophomore service classes (Physics I and II) were reorganized to provide course uniformity across different sections (syllabus, common exams, etc.) and continuity in their administration from one semester to the next. Introduced a one-hour problem solving recitation into what was previously a three-hour lab session.
- Offer two parallel courses in Physics I and II (separate labs, TA's and instructors), one of which uses the research-based Matter and Interactions program, which introduces computational modeling based on Visual Python.
- Reorganized schedule for physics majors in order to help introduce undergraduate research earlier. Undergraduate research thesis requires enrollment in Institute writing courses.
- Offer a certificate in Astrophysics and a new senior elective course on Cosmology/extra galactic astrophysics is being planned.

Indicators of success

- In the introductory courses, two types of student effort show strong correlations with success—class attendance and homework/additional problem load.
- Students who maintain a good class attendance rate (90% or better) are roughly 15 times likelier to earn a good grade (A or B) than to earn an unsatisfactory grade (D or F). For students with less than 90% attendance, less than half earn good grades while more than a quarter earn poor grades.
- The standard homework practice in the non-Matter and Interactions curriculum is to assign small daily assignments (3-4 problems, required) and a weekly supplemental assignment (roughly 10 problems, optional). Students who make a consistent effort to work the supplemental assignments are far less likely to earn a poor grade (under 5% D's and F's) than their peers who do not work the assignments (29% D's and F's).
- The standard homework practice in the Matter and Interactions curriculum is to assign small daily assignments (4-6 analytic problems, required) and a weekly computational homework question (also required). Required homework in the Matter and Interactions curriculum is not a strong predictor of student performance in the course. In addition, students are assigned weekly core skills development modules to strengthen basic skills (e.g., vector manipulation and free-body diagrams). Students must complete these modules quickly and accurately reaching a threshold number of correct problems per unit time.

Steps to sustain change

- Several General Faculty (non-tenure-track) play important roles in administration and instruction for Physics I and II and in UG advisement.

Issues

- Students enter the program with a wide variation in mathematical preparation and motivation.
- UG and graduate TAs are employed and trained separately for the two Physics I and II streams.
- Improve upper-division labs and maintain continuity/experimental development over the lab instructor cycle.

For more information contact

Brian Kennedy, Associate Chair for Undergraduate Program, **brian.kennedy@ physics.gatech.edu**

Case Study: Harvard University

Department description

- 35 tenure-line faculty members plus four full-time PhD lecturers
- Offers a BA in Physics and a BA in Chemistry and Physics
- 140 majors currently enrolled in the program from sophomore to senior year
- Over the last five years, graduated an average of 59 majors per year (combination of physics plus chemistry and physics)
- Over 600 students enroll in the physics sequences and other service courses each semester

Changes

- Completely changed pre-med service courses to better serve students in the biological sciences based on recent studies from the life sciences community; introduced biological examples and reworked labs to highlight biology. Pre-med course now uses calculus throughout.
- Flexible undergraduate physics program implemented by getting to know the students and helping them select courses that will allow them to achieve their career goals.
- On the basis of a survey of the physics faculty, identified six broad goals for physics concentrators: Physical Reasoning; Quantitative Analytical Techniques; Scientific Methodology; Communication; Independent Learning; Broader Impact of Physics.
- These skills constitute a "horizontal curriculum" that cuts across the traditional physics topics such as mechanics, E&M, Waves and Quantum Mechanics. The department is in the process of figuring out how to make these skills an explicit part of a student's education, perhaps by placing one faculty member in charge of the horizontal curriculum during all four basic courses.

Indicators of success

- Large numbers of majors, roughly half of whom go on to PhD programs in science.
- Pre-instruction and post-instruction testing shows increased learning in revised pre-med service courses.
- Student surveys in service courses indicate increased appreciation of the relationship between physics and biology.

Steps to sustain change

- Broad discussion of the undergraduate curriculum among faculty including those who are not directly involved in teaching undergraduates.

Issues

- Encouraging women and minorities to concentrate in physics.
- Educating students with widely different preparation and skills.
- Incorporating lab and other practical skills into the curriculum in a sufficiently exciting (or at least palatable) way.
- Keeping courses consistent from year to year as faculty change.
- Fitting requirements and prerequisites together in a sensible way.

For more information see (or contact): **http://www.physics.harvard.edu/**

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Logan McCarty, Director of Physical Sciences Education, **mccarty@fas.harvard.edu**

Case Study: University of Illinois at Urbana-Champaign

Department description

- 58 tenure-line faculty members
- 185 majors currently enrolled from sophomore to senior year
- Over the last five years, graduated an average of 51 majors per year
- 3800 students taught per semester in introductory physics sequences and other service courses
- Offers a BS in Physics, a BS in Engineering Physics, a BA in Science & Letters with a physics concentration and a BA in Science & Letters with a teaching of physics concentration

Changes

- Reform of very large introductory physics courses to increase student learning and insure consistency with a variety of faculty instructors. Reforms include peer instruction in all lectures, Just-In-Time-Teaching, collaborative learning in discussion sections, predict-observe-explain labs focusing on concepts, web-based homework with interactive examples, multiple choice exams created by all faculty. These changes necessitated intensive TA training and mentoring.
- Recently introduced web-based multimedia learning modules in the first-year calculus-based courses which students must complete before class and which contain the essence of a lecture. As a result, lectures become significantly more interactive.
- Introduced flexible curriculum with a physics core of six advanced courses plus other courses that students can tailor to meet their individual goals
- Modern experimental physics lab with three cycles, Nuclear & Particle; Atomic, Molecular & Optical; and Condensed Matter, all of which are taught by content expert faculty using networked digital scopes and electronic logbooks and stressing modern data analysis techniques
- A three-semester sequence of integrated research and instruction with the goal of preparing a senior thesis and developing skills in modern scientific communication

Indicators of success

- Over the last 10 years the number of physics graduates has increased from 24 in 2000 to 71 in 2010.
- In the last two years, enrollments in the senior thesis sequence have increased from 14 to 22.
- The PER group has carefully monitored student learning in the introductory courses and has demonstrated that the new interactive methods substantially increase students learning and improves their attitudes towards physics.

Steps to sustain change

- Strong departmental support with released time to make change and the creation of a new Associate Head position to oversee and continually improve undergraduate education
- Infrastructure created to sustain changes and bring new faculty members on board with interactive methods
- A culture change: Courses belong to the department (“our course”) not to individual faculty members (“my course”).
- A PER group created that serves as a source of continual change and new ideas and pedagogical methods

Issues

- Large increase in students (500 per semester) with fewer faculty, lower TA budget, and no new space
- Management of Undergraduate Research including finding summer funding, increasing faculty participation, matching faculty and students

For more information contact: Gary Gladding, Associate Head for Undergraduate Programs, **geg@illinois.edu**

Case Study: Massachusetts Institute of Technology

Department description

– 73 tenure-line faculty members
– 262 majors currently enrolled from sophomore to senior year
– Over the last five years, graduated an average of 83 majors per year
– 1000 students taught per semester in the introductory physics sequences and other service courses
– Offers a SB in Physics with two tracks possible

Students work in junior laboratory.

Changes

– Large freshman classical mechanics and E&M courses taught in TEAL format: A merger of presentations, tutorials, and hands-on laboratory experience into a technologically and collaboratively rich environment. The goal is to reduce passivity, develop collaborative learning, reduce the gender gap and develop new teaching/learning resources. Obtained new space for large TEAL courses based on North Carolina State's SCALE-UP model. Instructor is focused on student learning, not delivery of material. Integrated modular approach with online visualizations, peer instruction, interactive demos, desktop experiments and extensive problem-solving.
– A "Second Chance" option for those with a D (not a passing grade in the freshman year) in first-semester mechanics where students take an intensive three-week review in January and retake the exam with a chance to raise their grade.
– Offer mechanics in the spring and E&M in the fall for those who fail the first time through. The off-semester sequence includes with weekly tests and lots of tutoring.
– Introduced a course on the Physics of Energy whose only prerequisites are the freshman physics classes required of all students. This will be a required subject for students taking the new Energy Minor, to be launched soon.
– This spring (2010), offered a senior elective on symmetry in quantum physics.
– This coming fall (2010) will be introducing a new undergraduate course that will explore some of the societal and public policy questions that current scientific achievements raise. By considering topics including climate change and nuclear nonproliferation, this class will make the case that physics is a necessary part of the national discourse. There will be several long writing assignments.
– Next spring (2011) will introduce a capstone class for seniors in which students will analyze a few topics of current interest (for example, the physics of dark matter) in ways that draw together material from all the core subjects in our undergraduate curriculum.
– Ten years ago, introduced flexible option with fewer required physics courses but a requirement for an intellectually coherent three-course focus group which is tailored to the student's interest and may include courses outside of physics. Students can also take a focused option that is a more traditional physics major.

Evidence of success

– Pre-instruction and post-instruction testing show that TEAL method improves student learning and that classes have lower failure rate and higher retention to the second semester.
– Student reaction to TEAL has improved as faculty gain experience in the method, bugs are worked out, and students get used to an active-learning environment.
– Number of graduating physics majors has more than doubled since 2000 largely due to the flexible option.
– 33% of graduating physics majors are women.

Steps to sustain change

• Challenges for TEAL instruction include students' negative-to-neutral attitude towards active learning, faculty allegiance to the lecture format, and weak student math backgrounds. Therefore have guaranteed institutional support and a committed faculty leader to guide change; adapted methods to local environment; addressed faculty concerns; and provided students with clear learning objectives.
• Provide a culture that encourages innovation in teaching and pride in doing it well.

Issues

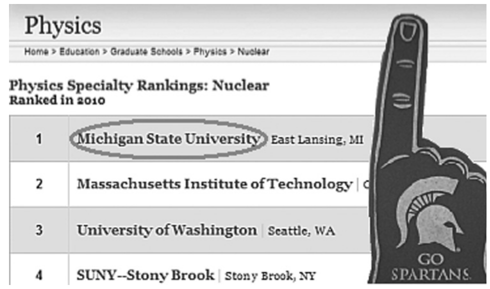
– Student and faculty resistance to TEAL method persists. Need to recruit more faculty members to teach in an active learning environment.

For more information: http://web.mit.edu/physics/ contact Professor Krishna Rajagopal, Associate Department Head for Education at **krishna@MIT.EDU**

Case Study: Michigan State University

Department description

- 55 tenure-line faculty members plus 13 full-time non-tenure-line faculty members
- 265 physics and astronomy majors currently enrolled from sophomore to senior year
- Over the last five years, graduated an average of 33 majors per year
- 1900-2000 students taught per semester in the introductory physics sequences and other service courses
- Offers a BS in Physics, Astronomy, and Chemical Physics and a BA in Physics and Astronomy



U.S. News and World Report 2010

Changes

- Got students into physics first thing in freshman year rather than insisting on calculus first and delaying physics until second semester.
- Revised first-year physics course to showcase modern physics research results and to use clickers.
- Introduced computation right away followed by a series of optional computer classes open only to physics and astronomy majors.
- Introduced new lab course for freshmen six hours per week where students can conduct non-cookbook labs with extensive faculty involvement in sections of six-eight students with topics in vacuum physics and optics.
- Introduced freshman seminar on energy.
- Got students into small classes to create community. Foster community through department social events. Active SPS chapter with departmental funding, weekly seminar and movie nights; Science Theater for outreach that is student-run, WAMPS (Women and Minorities in the Physical Sciences) chapter active.
- Supported active outreach programs including Science and Engineering Day, Grandparents University, Science Olympiad, PAN (Physics of Atomic Nuclei), Quark Net, the DUMP (high school teachers as partners in Developing User Materials and Problems for LON-CAPA online system), a newsletter, a website featuring undergraduates and recent alumni.
- A new building completed in 2002 for Microbiology, Physiology, and Physics and Astronomy with coffee shop on the first floor, Wi-Fi and lots of student spaces. The building is open on weekends.
- Provide outstanding incoming freshmen with $3000 stipend to work on research in the lab of a professor. The stipend can be renewed. Have 100 across the university each year and physics gets 6-8.
- Strong REU program.

Evidence of success

- Undergraduate enrollment in the program has increased from 139 in 2001-02 to 265 currently.
- Published textbook based on the first year course and the introduction of modern topics.
- Students receive a large number of awards (Goldwater, Marshall, Gates, Rhodes, NSF Graduate Fellowships, etc.).

Steps to sustain change

- Has recruited 10 female faculty members up from two in 2001-02.

Issues

- Freshman lab course is very expensive in terms of faculty time (four loads plus 2 TAs).
- Repeated budget cuts.

For more information contact:

Prof. Wolfgang Bauer, Chairperson, Department of Physics and Astronomy

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Case Study: University of Michigan – Ann Arbor

Department description

Photo from University of Michigan Physics Dept.

- 55 tenure-line faculty members plus eight part-time lecturers
- 131 majors currently enrolled from sophomore to senior year
- Over the last five years, graduated an average of 37 majors per year with a large increase to 51 in 2009
- 2000 students taught per semester in the introductory physics sequences and other service courses
- Offers a BS in Physics, an Honors Physics BS and an Interdisciplinary Physics BA/BS

Changes

- Recent change of structure in core introductory courses because of resource limitations. Starting Fall 2010, courses will meet four days a week in sections of 200 rather than traditional two-day lecture, two-day small section format. Need interactive techniques including peer instruction and clickers to sustain students' learning under this new format.
- Restructured the introductory Honors physics course based on Matter and Interactions, which introduces modern topics and computation for physics majors. Students were not enrolling in honors introductory physics and were bored in regular courses, so did not become physics majors.
- Introduced a new introductory physics course for students in the life sciences. The new course emphasizes topics such as fluids, thermodynamics and statistical physics as well as introduction to newer topics such as cosmology.
- In the process of designing a new course for students who are unlikely to pass introductory physics course, aimed at strengthening their math skills and providing practice.
- Flexible curriculum backed by individual advising that allows student and advisor to create an individually tailored plan for Interdisciplinary Physics major.
- Very active SPS chapter that has created vital outreach effort for the department.
- Active recruiting including campus visits and meetings with faculty, large demonstrations for local schools, Saturday Morning Physics, Physics Olympiad.

Evidence of success

- Recent growth in numbers of physics majors.
- Shift in population in introductory physics with more students in honors introductory physics course.

Steps to sustain change

- Regular faculty meetings over the summer are being used to develop approaches to the new introductory course delivery model. These meetings will continue during the upcoming terms.
- Working to establish a larger pool of faculty experienced in teaching the introductory courses. Discussions are ongoing with our Center for Research on Learning and Teaching to create sustainable assessment mechanisms.

Issues

- Continuing growth of number of physics majors
- Sustaining faculty involvement in change as the new structure of the introductory physics becomes established
- Developing labs for the new life sciences courses.

For more information see (or contact)

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Case Study: Pennsylvania State University

Department description


SPS celebrates Halloween

- 40 tenure-line faculty members plus four full-time non-tenure-line faculty members at the main University Park campus. Some students spend the first two years in pre-major status at one of the 19 smaller distributed campuses
- 132 majors currently enrolled from sophomore to senior year
- Over the last five years, graduated an average of 36 majors per year of which about 1/3 transfer from another campus or university
- 3000 students taught per semester in the introductory algebra/trig- and calculus-based physics courses plus conceptual physics course
- Offers a BS in Physics with general, medical, and electronics options, plus planned options in Computational Physics, Materials Science, and Nanotechnology while phasing out options in acoustics and teaching

Changes

- Now has one "point of contact" for all undergraduate advising with a person who is also the SPS, Study Abroad and COOP advisor and who teaches the freshman seminar and junior career advising course.
- Introducing several new options (computational physics, materials science, and nanotechnology) for the major that have been mapped out this year and will be submitted for formal approval next year.
- New courses in Special/General Relativity and Medical Physics.
- Updated junior "research" course into a required two-credit course in the spring of the junior year featuring outside speakers as well as faculty members, career advice, lots of homework, but not math-intensive kind, including preparation for the General GRE, Praxis, and Major Field Tests and collection of career information.
- Very active SPS chapter.
- Large lounge space set aside for students and shared (peacefully!) by grad students and undergrads.
- Undergraduate research opportunities (or experiential learning of some type, including TA work, internships, COOP, etc.) for almost all students.

Evidence of success

- Over the last three years, students' assessment of advising has been at least 97% very positive.
- Students' opinion on career advising is 50% very positive and 29% positive in a 2010 survey.
- Students' access to early research opportunities has led to physics majors receiving Schreyer Honors College Awards, Goldwater Scholarships, NSF Graduate Fellowships, NDSEG Fellowships, NPSC Fellowships, Marshall Fellowship, Cambridge NIH Fellowship, and 3 AAPM Summer Fellowships in the last three years.

Steps to sustain change

- Create an active undergraduate program committee to assess undergraduate curriculum and courses and take the lead in proposing change.
- Keep track of the careers students choose (currently ¼ to grad school, ¼ to industrial employers, ¼ to government (or related) agencies, and ¼ to teaching) and post results on web page.

Issues

- Economy downturn means that students are focusing on majors that are more "saleable" in the job market.
- Financial issues make it hard for ALL students to attend the university.

For more information

see **www.phys.psu.edu/undergraduate**

or contact Prof. Richard Robinett, **rq9@psu.edu**

Case Study: Princeton University

Department description

– 29 tenure-line faculty members plus 12 full-time non-tenure-line faculty members
– 96 majors currently enrolled from sophomore to senior year
– Over the last five years, graduated an average of 23 majors per year
– 550 students taught per semester in a variety of courses including the introductory physics sequences
– Offers a BA in Physics

Changes

– Made major changes to calculus-based introductory sequence including switch to online and therefore graded homework, clickers in lecture, and reduction in content.
– Revitalized sophomore mechanics course for those students who did not take the honors freshman sequence to make it different from the course taken by those who did take the honors sequence and not just “easier.”
– Contact all freshmen who express an interest in physics; shadow advising, and run a sophomore seminar to emphasize real-world problems, not the traditional theoretical ones.
– Overhaul conceptual physics course to emphasize more modern topics, technical issues facing citizens and policy-makers.
– All undergraduate majors are involved in research. Require three independent work projects for all majors: two junior papers plus a senior thesis, each with individual faculty advisor. Independent work requirement puts faculty into contact with undergraduates in a research environment and integrates the teaching and research sides of the department. Faculty experience with undergraduates leads to faculty interest in hiring undergrads so that around 30 work in the department each summer and that becomes a recruiting ground for potential majors.

Evidence of success

– Number of graduating majors has increased from 14 in 2000 to 28 in 2010.
– A modest flow of majors into physics from the revised general calculus-based sequence.

Steps to sustain change

• Established a “recruiting czar” to be shadow advisor, watch admissions, and be sure that majors are recruited from the general calculus-based physics sequence.

Issues

– Basic calculus-based course and pre-med course still need work so that students who are pressed for time will engage with physics. Use of online homework system needs tuning to avoid reinforcing bad practices (guessing, blind use of not-understood formulas, …).
– Freshman labs are a perennial problem: have tried open-ended, multi-week formats but didn’t work well in general calculus-based course.

For more information contact

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Lyman Page, **page@Princeton.EDU**

Case Study: Purdue University

Department description

- 52 FTE tenure-line faculty members
- 149 majors currently enrolled from sophomore to senior year
- Over the last five years, graduated an average of 27 majors per year
- 3500 students taught per semester in the introductory physics sequences and a variety of other service courses
- Offers a BS in Physics, Physics Honors, Applied Physics, Applied Physics Honors, and Physics Education

Changes

- Four years ago, the introductory sequence for the majors was changed to the Matter and Interactions approach which immediately introduces computational physics and from a three-semester sequence to a two-semester sequence.
- Calculus made a co-requirement for intro physics so students could start it immediately in their freshman years.
- The upper division curriculum was updated so that the first two years of all five major programs are the same and they all include two courses in mathematical physics to prepare students for difficult junior year work and to provide a flexible curriculum to meet students' varied goals including the opportunity to take specialty courses in both physics and other disciplines.
- Added many dual-level (graduate-undergraduate) specialty courses.
- Have tried to adapt the applied physics program to make it easier for students to double major in fields such as mechanical engineering.
- Worked to expose freshmen to research.
- Sophomore level modern physics course redesigned and increased to four credits.
- Replaced a required optics only course by more general one on waves and oscillations.
- Tracking students as they start careers: 67% to graduate school in physics or other fields; 21% with jobs in industry; 7% with government and 5% to teaching.
- Ascarelli Fellowships support undergraduate research beginning in freshman year.

Evidence of success

- Majors in applied programs increasing steadily while enrollment in regular programs holding roughly steady.
- Half of students polled memorably enjoyed at least one physics course, and 75% would choose to major in our Department again if they could start over.

Steps to sustain change

- Assessment of new curriculum under way but still a work in progress.

Issues

- Recruitment and retention of highly qualified students; Only 40% of students entering as freshman physics majors graduate in physics, compared with 30% for those entering the College of Science as freshmen and graduate from the College of Science.
- Dealing with the range of mathematical preparation of incoming students.
- Need better roadmap for the Applied Physics programs in various areas.
- Modernization of labs needed.
- Need better publicity and support for undergraduate research on campus.
- Only 12% of physics majors are female and about 12% are underrepresented minorities.
- Allocation of TAs largely dictated by engineering enrollments and the department badly needs more.

For more information contact Janice Thomaz, Academic Counselor, **thomazj@purdue.edu, 765-494-5383**
Hisao Nakanishi, Associate Head, **hisao@purdue.edu, 765-494-5522**

Case Study: Rutgers University

Department description

- 65 tenure-line faculty members and one full-time, non-tenure-line faculty member
- 130 majors currently enrolled from sophomore to senior year
- Over the last five years, graduated an average of 36 majors per year
- 3000 students taught per semester in the introductory physics sequences and a variety of other service courses
- Offers BS and BA in Physics with four options: professional (34%), applied physics (20%), astrophysics (14%), and ocean physics (just introduced) plus a BA that is a general option in preparation for high school teaching, business etc. (32%)

Changes

- Introduced a new Major Option in Ocean Physics at the request of the Department of Marine Sciences.
- Flexible programs meet varying needs of students.
- Reformed courses and unusual advanced general physics course option.
- Single adviser for majors to ensure consistency of advice, and avoid disruptions because of sabbaticals. Adviser gets to know all majors very well.
- Research opportunities abound for majors doing Professional Option and Astrophysics major.
- There are seven $7500 merit-based scholarships each year, exclusively for physics majors, and selected by the Physics Department. Two of these are reserved for women majors.
- Active recruitment of high school seniors who have been accepted by Rutgers: Open House, Scholars Days, Scarlet Days, etc.
- Annual student-faculty banquet, heavily subsidized.
- Active SPS Chapter including monthly speakers, with free pizza and sodas; GRE study sessions; field trips; and two barbecues for whole department.

Evidence of success

- Physics graduates have increased from 32 per year in 2005 to 45 in 2010.
- Students are accepted into very good graduate programs and they find excellent jobs in industry.

Steps to sustain change

- Six staff members support undergraduate program with two staff members assigned to run all aspects of the introductory labs including development and write ups as well as TA training and setting up advanced and intermediate labs; one staff member to handle lecture demonstration support and to do VERY extensive outreach; one staff member to handle all aspects of our reformed introductory sequence, including giving lectures, teaching one workshop and one lab section, training and supervising TAs, doing setups for labs and for lecture demonstrations, etc.; one staff member to teach our primary algebra/trig-based sequence, as well as our sequence for at-risk students. That person also has responsibilities outside of physics; one staff member to teach and run all aspects of our reformed course for at-risk engineering freshmen. That person also has responsibilities outside of physics.
- Established a close collaboration with faculty in the Graduate School of Education and other departments as evidenced in staff responsibilities.
- Single advisor system has worked very well and has been institutionalized.
- Specialized introductory sequence for at risk students has worked very well and been institutionalized.

Issues

- Only 24% of our majors are women; only 5% of our majors are Black or Hispanic.
- We lose contact with too many of our majors after graduation.

For more information contact: Prof. Mohan Kalelkar, **kalelkar@physics.rutgers.edu**

Case Study: Stanford University

Department description

Photograph by Angela Drury

- ~30 tenure-line FTE, which equals ~40 people because of joint appointments with Applied Physics and SLAC
- ~90 total majors enrolled, from sophomore to senior year
- Over the past five years, graduated an average of 27 majors per year
- ~600 students taught per quarter in the introductory physics sequences plus astronomy.
- Offers a BS in Physics, a BS in Engineering (Engineering Physics), and a BA in Teaching Physical Science.

Changes

- Two years ago, embarked on a major effort to revamp the pedagogy (not so much the curriculum/topics) in the introductory physics courses.
- Took a year to plan the changes: formed a committee of faculty, teaching staff, grad student; surveyed students, TAs; ran faculty focus groups; studied Physics Education Research literature; assembled case studies of efforts at other institutions and interviewed initiators of seven of these efforts asking about resources invested, the results of assessment, and the sustainability of the effort; described recommendations in a detailed report; presented report to faculty for vote of support and gathered financial resources.
- In year two, implemented structural changes including rooms for sections—location and acoustics matter; new furniture—small tables, movable chairs; new section sizes, scheduling—often run sections in parallel now, in adjacent rooms; began revision of labs: predict, measure, explain; introduced small-group problem solving in discussion sections; continued to provide support for clickers in lecture.
- In year three, refined reformed pedagogy: use a variety of exercises in discussion sections including tutorials, research-based simulations (PhETs), hands-on exercises, context-rich problems, old exam problems; gathered feedback from TAs after each discussion section; gathered frequent feedback from students; use pre- and post-lab assessments to determine whether students are learning concepts; enlist talented, motivated graduate students to mentor TAs, organized and d small-group mid-quarter evaluations, etc.
- Offer summer research opportunities for physics majors; university supports them with a stipend of $5600 for 10 weeks.
- Added a BA in teaching physical science in 2004, an engineering physics major in 2006, and a minor in education in 2009.

Evidence of success

- More faculty using interactive engagement in lectures: mostly clickers; one uses JiTT; some use of PhETs (with clickers) in lecture.
- Graduate students engaged in discussions of pedagogy, teaching and learning!
- More use of undergraduate TAs—sometimes very successfully.
- Higher attendance in discussion sections; growing appreciation of interactive discussion sections.
- Higher student satisfaction with laboratories.
- Some instructors and TAs now using interactive learning approaches in courses for physics majors and grad students.

Steps to sustain change

- Hired full-time Physics Education Specialist: essential!
- Invited four national figures in Physics Education Research to give workshops and/or seminars.
- Continuously educate the students we are teaching on the purpose and goals of the techniques we are using.

- Train and continuously mentor the Teaching Assistants.
- Engaged volunteer School of Education graduate students with physics backgrounds and interests.
- Institutionalized weekly meetings between Physics Education Specialist, TAs and instructor; engagement of instructor varies.

Advice on making change

- Ask for well-motivated (modest) institutional support: Our Dean has welcomed the fact that we are asking for resources to improve student learning. We emphasize that enrollments in the introductory physics courses are increasing. Currently, over one third of Stanford students take one of the introductory physics sequences.
- Talented, motivated graduate students are an incredible resource to leverage as teaching mentors and in developing or refining materials.
- Take advantage of efforts in other departments.

Issues

- It is difficult to identify effective instructors for all the reformed courses and to engage some faculty in the reformed pedagogies.
- Recruitment and retention of students who are underrepresented minorities, female, or first-generation college students remains a challenge.

For more information see (or contact)

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Case Study: University of Toledo

Department description

SPS with Rube Goldberg Machine

- 20 tenure-line faculty members with searches approved or in progress for four additional tenure-track faculty lines
- Two visiting full-time faculty members with ongoing searches for two additional visiting faculty
- 62 majors currently enrolled from sophomore to senior year
- Over the last five years, graduated an average of 11 majors per year (including both physics and astronomy majors)
- Over 2100 students taught per semester in physics, astronomy, and physical science courses
- Offers a BS in Physics with optional concentrations in either applied physics, astrophysics, or biomedical physics, a BA in Physics, a BA in Astronomy, and undergraduate minors in Physics, Astrophysics, or Renewable Energy

Changes

- The department encourages undergraduate research by getting students involved as soon as possible, and a departmental colloquium slot is reserved for presentations of undergraduate research. The department also offers an annual prize for undergraduate research and hosts a strong REU (Research Experience for Undergraduates) program.
- The department supports an active SPS chapter by providing a small budget as well as a lounge. SPS activities include outreach to local schools, social events like movie-game nights or picnics, and special events such as Rube Goldberg and solar car contests.
- Curriculum revisions include the addition of BA degrees in Physics and Astronomy, the addition of a biomedical physics concentration in the BS, and the addition of an interdisciplinary minor in Renewable Energy.
- Introduction and revamping of a freshman course “Frontiers in Physics and Astronomy” that is team-taught by a physicist and an astronomer to motivate students about the excitement of physics, and to introduce them to the department, the advisors, and career opportunities in physics. All students in the course must do a semester project, including both written and oral components, to build professional skills.
- The department has a single advisor for all majors; senior exit interviews are routinely conducted with all graduating seniors.
- Merit-based departmental scholarships are awarded annually. Small competitively awarded research grants are also available from the university-wide Office of Undergraduate Research, which offers funding for students during academic year and summer.
- Diversity efforts: Faculty of the Department have been founding members of a new chapter (Northwest Ohio Chapter) of the Association for Women in Science (AWIS); the department also provides support for the WISE (Women in Science and Engineering) mentoring program, and several graduate students and faculty members act as mentors for young women who are science majors. The department chair is a participant in the NSF-funded IDEAL program, led by Case Western Reserve University, along with five other Ohio universities—this program aims to increase diversity among faculty in STEM areas.
- Outreach to local high schools includes a post-secondary option for local H.S. students with dual credit options. A new program offers courses that provide UT credit while being taught at the high school.
- The department also hosts a summer physics camp for H.S. students (tied to REU).

Evidence of success

- Number of majors enrolled in the program has gone from about 34 in 2007 to 62 in 2009.
- Undergraduates involved in research appear as co-authors on published papers.
- The university has made recent strategic investments in two key research areas in department (photovoltaics and astrophysics) which have had major impact on research activity level, and also on number and quality of majors attracted to physics and astronomy.

Steps to sustain change

- Expanding use of clickers and interactive teaching methods in large lectures.
- Expanding use of Webtools such as BlackBoard to put lectures online and develop web-assisted courses.
- The department is considering reorganizing recitation sections to make them interactive and/or inquiry-based.
- Developed additional facilities for community outreach (including to underserved communities in the area), including upgrading the department planetarium.
- Consider the development of a "flexible-option" major.

Issues

- Many first-generation college students, many from rural or inner-city schools. Also large proportion of "non-traditional students."
- Open enrollment policy leads to a large range of levels of student preparation and requires the department to tailor individual tracks based on academic background.
- Growing demand for algebra-based introductory courses for pre-med, pre-physical therapy, pharmacy, life sciences, and less prepared science majors.
- Large service load: example—introductory astronomy courses are widely taken by education majors. However this also provides an important opportunity for recruitment.
- There is significant attrition in the number of Physics and Astronomy majors in the freshman and sophomore years—need to work on mentoring to help retain a higher fraction of entering freshmen.
- Smaller faculty size places limits on ability to offer large range of specialty courses for multiple tracks. How do we customize without adding new courses?
- Lack of sufficient resources (faculty, staff, teaching space, office-space, laboratory space, TA's, etc)

For more information contact:

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Case Study: University of Virginia

Department description

- 34 tenure-line faculty members plus two full-time, non-tenure-line faculty members
- 94 majors currently enrolled from sophomore to senior year
- Over the last five years, graduated an average of 36 majors per year
- 1620 students taught per semester in three physics sequences plus a variety of courses for non-science majors
- Offers a BA in Physics, a BA Distinguished Major Program in Physics, a BA in Astronomy/ Physics (joint program with the Astronomy Department), and a BS in Physics

Changes

- Changed the content of our two courses on Widely Applied Physics to focus on energy production and use.
- Offer substantial research options for physics majors which are required for students in the BS, BA/DM and BA/ PA majors.
- Introduced new concentrations in Energy and Computational Physics.
- Focus on two introductory and two intermediate majors' labs which are taught with eight students per section to bring students into close contact with faculty

Evidence of success

- Very large enrollments in courses designed for non-science majors.

Steps to sustain change

- Some additional resources for majors' labs; Program Committee to investigate resource impact of implementing ideas from SPIN-UP meeting.

Issues

- Getting lines to hire new faculty to bring the department back to its original strength.
- Staffing the upper-level labs which now require several faculty members each semester.
- Space required to implement changes will entail reallocation of existing space.
- Concern that growth in number of majors has stagnated at level below what we feel is appropriate for a student body of our size.

For more information contact

Blaine Norum, Assoc. Chair for Undergraduate Programs, **434-924-6789, ben@virginia.edu**

Case Study: Yale University

Department description

- 35 ladder faculty members plus two full-time, non-ladder faculty members
- Over the last five years, graduated an average of 29 majors per year
- 600 students taught per semester in a variety of courses including both an honors sequence for well-prepared students and a regular and larger calculus-based physics sequence.
- Offers a BS in physics and a BS (intensive for graduate-school-bound students) in physics

Changes

- Reworking the introductory physics course for life science majors to make it more relevant to those students and to meet the new focus of the life science community; labs being reworked to use examples that are important in life sciences.
- Introduced evening help sessions for homework and lab classes.
- Use of clickers in some large lectures.
- More summer research fellowships for summer undergraduate research with faculty.
- Outreach K-12 students through programs for girls and underrepresented minorities.
- Participating in summer science internships for high school students with local community groups; summer tours of research labs for community and students; increased emphasis on Yale Physics Olympics.

Evidence of success

- Increased student participation in Yale Physics Olympics.
- Summer science research fellowships from Yale for students more than tripled.

Steps to sustain change

- Yale University administration supports the changes described above, including increased funding for science students.

For more information contact

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