Sustaining physics programs through interdisciplinary programs: A case study in nanotechnology

Many of the nation's physics graduates come from bachelor's granting institutions with small physics programs; of 505 bachelor's granting programs, only 52 have 10 or more graduates each year.[1] The current economic downturn is putting pressure on administrators to close low-enrolled programs. This emphasis on dollars and cents, combined with the high cost of equipping and maintaining laboratories and faculty lines, threatens the many small programs that collectively account for about 40% of all physics graduates each year.[2]

The Pennsylvania State System of Higher Education is not immune from these pressures. Programs that averaged less than 6 students per year for the past 5 years are deemed "low enrolled" and are subject to review. Of the 14 universities in our system, the smallest university already does not have a physics major. Of the 13 that do, 10 are low enrolled and one has been designated for closure in 2011 and tenured physics faculty given letters of retrenchment. The remaining programs are scrambling to develop strategies for survival, including collaboration with other schools and online delivery of low-enrolled upper division courses to reduce costs. If fewer than 6 graduates per year becomes the criterion for a low-enrolled program, 73% of the 505 bachelor's-only degree granting institutions in the U.S. is "under enrolled." Some, if not many, of these programs might be eliminated or significantly scaled back to the status of a "service" discipline unless they take active steps to increase enrollment. In these times the benefits to students of a thriving physics program are often secondary to the bottom line.

We describe here the steps we took to grow our B.S. Physics program from an average of 1.5 graduates per year (ten year average) to an average of 7.2 graduates per year (five year average) by integrating nanotechnology into the curriculum. Our department now produces the third highest number of physics graduates in our 14 university system despite the fact that we are the third smallest in total undergraduate enrollment (5450 students).

Applied physics and minor in nanotechnology. In 2003, we recognized the need to attract nontraditional students to the physics program by developing an applied physics track that incorporates nanotechnology into the physics curriculum. By 2008, we saw that a significant number of biology and chemistry majors were becoming interested in nanotechnology and applying it within their disciplines. The recognition that the tools and techniques of nanotechnology have applications across disciplines presaged the growing trend toward "convergence science,"[3] prompting us to develop a minor in nanotechnology for biology and chemistry majors. The minor piggybacks on the curriculum we developed and implemented for the applied physics program, and enhances that program by helping populate new upper division courses.

Applied physics helps students acquire knowledge and skills that they will need in the workplace: Working in teams, applying the scientific method, and becoming active and continuous learners.[4] To support the applied physics track, we developed several new courses: Introduction to Nanoscience Seminar,[5] Thin-Film Science, and Advanced Laboratory/Research Experience, all of which highlight the interdisciplinary nature of nanoscale physics and are taught at a level that prepares students for graduate school or industry. The curricular and laboratory developments for this applied physics track are similar to developments in undergraduate materials science programs.[6,7] The challenges of adapting and delivering courses, such as Thin Film Science to classes comprising a mix of physics, biology, and chemistry majors, are outweighed by the opportunities to enrich the student experience with different perspectives. Physics majors, for example, are introduced to biofilms and polymer based films.

We further augmented the nanotechnology courses by requiring students minoring in nanotechnology and students majoring in applied physics (nanotechnology) to spend a summer semester at Penn State University's Center for Nanotechnology Education and Utilization, typically at the end of their sophomore year. This program is offered at Lock Haven University tuition rates and is located only 40 miles away from the main Penn State campus. We also aligned our physics program with the engineering science and mechanics program at Penn State University through a 4+2 agreement, whereby graduates who earned a 3.4+ GPA can enter the Engineering Science masters program at Penn State University, receive favorable consideration for a full teaching assistantship, and earn a master's degree in two years. This incentive has been important for recruiting outstanding physics majors to our program. Since it was implemented in 2005, we have sent five applied physics graduates to Penn State University under this agreement. One student defended his Ph.D. dissertation in December 2010, and two have completed their M.S. and two are still in graduate school. We created and continue to foster a student-run learning community called the Nano Club that helps retain students in all sciences. These activities are described in Ref. 8.

By offering increasingly sophisticated research opportunities, beginning with basic literature reviews in the introductory nanoscience seminar[8] and progressing to independent research with faculty mentors, we keep applied physics students engaged and focused. Since expanding the Nanotechnology curriculum to other science majors through the minor in Nanotechnology we have collaborated with faculty colleagues in biology and chemistry to develop meaningful interdisciplinary research opportunities using the tools and techniques of nanotechnology.

Undergraduate research opportunities. By using a sputter coater, a spin coater, and an atomic force microscope (AFM), students have investigated the self-assembly[9–12] of noble metal (for example, Ag and Au) nanoparticles[13,14] on Si surfaces using sputter deposition.[15–17] These systems are easily fabricated and are complex surface systems rich in physics and chemistry. They introduce students to surface physics and the "bottom up" approach in nanostructure design. Self-assembly of these structures is tied to the surface, evaporant, and rate of evaporant.[18] The observed morphology provides an interesting entry point into discussions of crystal structure, surface energies, diffusion, and a plethora of rich physiochemical concepts of solids and their processes.

Our collaborative, interdisciplinary approach enhances students' research experience. Chemistry majors approach investigations with the basics of crystal structure and a "picture" of the system, while physics majors have a better grasp of the mathematical constructs underlying the thermodynamic and kinetic processes in the systems. By encouraging and facilitating students to work together, physics majors gain insights into the richness of the surface processes, such as physisorption and chemisorption, and are guided to connect the dynamics expressed by the pertinent equations into models, while chemistry majors go through the inverse process of connecting models to equations. Discussions become more lively and engaging. By strategic partnering of sophomores with juniors and juniors with seniors who are better versed with the instrumentation and equipped with the necessary scientific depth, we develop leadership skills, foster camaraderie, instill confidence in articulating and expressing scientific thought, and establish a peer learning community among our students.

In another investigation, students study the growth dynamics and biomechanical properties of fungi spores using contact/tapping mode AFM. Fundamental biophysics of the fungi is explained via the fungi outer structure.[19,20] This collaborative investigation between physics and biology faculty exemplifies the multifaceted approach in nanotechnology.

By using the scanning electron microscope, electron dispersive x-ray analysis, chemical vapor deposition system, and a thermal evaporator, students have also conducted research in polymer light-emitting diodes,[21,22] dye sensitized solar cells,[23] synthesis of zinc oxide[24] and iron oxide nanoparticles,[25] chemical vapor deposition of nanoparticles,[26,27] automation of physical experiments, fabrication and characterization of a thin film nanocapacitor,[28,29] synthesizing of nanophosphors,[30–33] and optical studies of bacteria.[34] The success of many of these projects is based on creating permanent experimental setups that are fully computer controlled. The tight schedule of the undergraduate curriculum requires formulating individual tasks for each 3 h laboratory session that can lead to tangible results at the end of the session. This task is sometimes challenging because the experiments are exploratory in many cases.

Enrolling Biology, Chemistry, and Health Science students who have not had foundational courses in solid state physics and molecular physics requires adapting course content and delivery. Topics are introduced on a conceptual level tailored to students' level of preparation and more advanced concepts are introduced as they become relevant to research projects. A typical example is the topic of polymer light-emitting diodes.[35] The active material in polymer light-emitting diodes is a conjugated polymer with a distinct color. The explanation why it is called "conjugated" and the origin of the color, which is related to the conjugation length, requires reference to introductory chemistry and physics and an introduction to concepts from quantum mechanics. Another research topic is dye sensitized solar cells, where the preparation of the titania paste allows us to discuss aspects of colloidal chemistry and the underlying electrostatical phenomena.

The presence of students from multiple disciplines has not compromised course rigor in the applied physics track; if anything course content is enriched by their presence. One measure of the quality of the resulting educational experience is our graduate school placement rate. In the past five years, the applied physics track has placed seven students into graduate schools in engineering (at Penn State, Georgia Tech, and Bucknell), a nearly 60% placement rate. In contrast, only four students from the traditional physics track have gone on to engineering and physics graduate schools in the same period, a 30% placement rate.

In 2010, we developed a new agreement with SUNY Upstate Medical University for entrance into Ph.D. programs in biomedical research, open to students who have completed a year of biology, chemistry, and physics and who graduated with a high GPA in any science major. SUNY is particularly interested in applied physics graduates who want to pursue careers in biomedical research, further evidence of the rapidly growing convergence of life sciences, physical sciences, and engineering[3] and validating our strategy of opening nanophysics to undergraduates in all science disciplines. We expect that such agreements will draw more nontraditional students to our applied physics track, as our 4+2 agreement with Penn State University attracted more engineering students to applied physics.

Nanotechnology, which is inherently interdisciplinary, is the approach we used to grow our physics department. Other universities could tap into the interdisciplinary nature of materials science or biophysics to develop equally effective programs to increase the number of physics students and graduates. We developed new pathways for both nonphysics majors and physics majors and linkages with graduate programs to help recruit students. We have emphasized two themes: The applied aspect of physics and collaborative interdisciplinary education.

In the applied physics track, we try to enroll students initially interested in applications of physics, and students interested in engineering but inclined toward the broader education given by basic physics courses. In this way, we respond to the needs and interests of these students and recruit them to physics. By emphasizing the practical relevance of the concepts taught in specific physics courses (for example, mechanics, electricity, magnetism, and quantum mechanics), we are able to recruit these nontraditional physics students into our program.

These changes were not introduced without concerns about content and quality, based on the belief that only the brightest and most mathematically gifted students can survive the more specialized physics courses. This understanding has its natural roots in traditional, rigorous physics programs like ours. However, our students' success at the graduate school level has demonstrated that, by adapting appropriate pedagogy and learning goals, we can recruit nontraditional students to physics and help them succeed.

Collaborative interdisciplinary education using the minor in nanotechnology has opened our laboratories to students from biology, chemistry, and health sciences. To exploit the interdisciplinary focus (in our case nanotechnology), the support of faculty members in the other sciences is crucial. We obtained their buy-in through collaborative research involving faculty and students from multiple disciplines.

We have done many things to grow our program in the last few years, beginning with recruiting faculty with the vision to see the potential of recruiting students from outside traditional physics. We articulated the benefits to students in all the sciences (not just physics), expanded undergraduate research experiences to interdisciplinary topics, and negotiated external agreements with graduate programs. To institutionalize these efforts, we obtained administration support by emphasizing the benefits to students, and we created a student-run learning community open to students from all science disciplines (Nano Club). Other thriving physics programs have also found that the synergy of these combined efforts is what makes a physics department flourish, although implementing and institutionalizing them takes time.[36] We have shown that an interdisciplinary approach, combined with the comprehensive strategy we described, can significantly contribute to the growth, and perhaps the survival, of small physics programs.

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