Graduate Education in Physics: The Path Ahead

A Conference to Discuss the Status and Future of Graduate Education in Physics

January 31–February 2, 2013
American Center for Physics, College Park, Maryland

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The Path Ahead

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Executive Summary

Directors of graduate studies and department chairs from 74 physics departments convened at the American Center for Physics from January 31 to February 2, 2013 for the second conference on graduate education in physics. They were joined by representatives from industry, national laboratories, and professional societies (including a European representative), and 11 graduate student leaders. The meeting, which followed up the 2008 graduate education conference, was organized by the American Physical Society (APS) and the American Association of Physics Teachers (AAPT) with partial National Science Foundation (NSF) funding. Attendees shared best practices and discussed how to spur innovation and creativity to improve graduate education in physics and address challenges and opportunities facing the discipline.

One of the major challenges physics faces is a persistent inability to engage students from underrepresented minority groups. These students represent an increasing fraction of the US student population. Another challenge facing graduate programs is that approximately 50% of the physics PhD degrees in the U.S. are awarded to foreign students[1], and with countries such as China and India strengthening their own science research infrastructure, the competition for the best foreign physics graduate students at U.S. universities is likely to increase. Both challenges have implications for recruiting a pool of highly-talented future physics graduate students. Recommendations to increase diversity in physics include:

- *Increase efforts to recruit diverse students*
- *Develop admissions criteria and exam structures that promote innovative and highly motivated researchers*
- *Build bridge programs of the type that APS is helping to develop and replicate*[2]
- *Establish cohorts with a critical mass of underrepresented students*
- *Employ research-based curricula and pedagogies in core courses*[3]
- *Provide effective and vigilant mentoring and monitoring of student progress (including training faculty in these skills)*[4]
- *Establish or improve family-friendly policies for graduate students*
- *Provide social/cultural resources and support for all students*

Sessions also focused on preparing students for diverse careers. Physics is becoming more interdisciplinary, and representatives from many departments reported they have begun to modify their curricula and exam structures in order to accommodate interdisciplinary research and interests. Participants also agreed that physics graduate education should provide adequate training for non-academic careers, since a majority of physics graduate students (approximately 70%) will end up employed outside academia. Industrial and national lab representatives emphasized that physicists prepared with in-depth knowledge in some areas of physics, broad knowledge across the discipline, and professional skills, can adapt more readily to new situations and a rapidly changing work environment. Recommendations to improve the professional training of students in physics graduate programs include:

- *Develop a distinctive department identity*
- *Add flexibility to the curriculum*
- *Teach students a wide range of professional skills, including oral and written communication, networking, program management, leadership, and the ability to work in and lead teams*
- *Engage alumni working outside of academia*

This report expands on these recommendations. The APS and AAPT gratefully acknowledge the support of the National Science Foundation in helping make this conference.

Key Findings & Recommendations

The following key findings emerged from discussions and presentations at the conference. They include input and feedback from the participating graduate students, whose active engagement contributed to the success of the conference. The recommendations build upon, and in some cases reiterate, the observations and recommendations from the 2006 report of the Joint AAPT-APS Task Force on Graduate Education in Physics[5] and the report from the 2008 Graduate Education in Physics Conference: "Graduate Education in Physics: Which Way Forward?"[6]. The evolution of graduate education in physics is an ongoing process, and one overarching theme that emerged from this conference is that physics departments should define their overall goals, in order to develop coherent programs that build on their specific strengths, rather than seeking a one-size-fits-all-departments solution. While the recommended actions described here may not be appropriate for every department, they can enrich physics graduate programs if implemented in a way that aligns with departmental goals and strengths.

Develop an identity for your graduate program

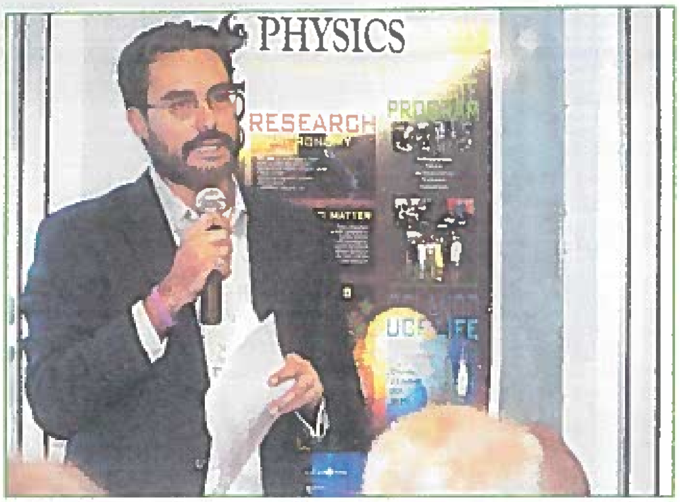
In order to develop a coherent strategy, faculty must know the strengths of their department and the goals for their particular graduate program. There is no "one-size-fits-all" solution; rather, each department must define itself and highlight the unique strengths of its program in a coordinated fashion. These strengths should then be appropriately advertised, so that students can make informed decisions about graduate school based on their own goals, skills, and ambitions. Conference participants also recommended that APS and AAPT include experts on graduate school issues in their lists of potential physics department reviewers, in order to help departments that would like to initiate a comprehensive review of their programs. Physics departments should convene advisory and review boards with demographics similar to the graduate program demographics they aspire to.

Strive to achieve diversity in recruitment and admissions

In 2011, women earned 18% of U.S. doctoral degrees in physics[7]. African Americans, Hispanic Americans, and Native Americans claimed only 6% of doctoral degrees in physics awarded to U.S. citizens and permanent residents, while representing about 35% of the population of the age of the average graduate[7,8]. Effective recruiting of women and minorities is critical if U.S. graduate physics programs want to stay competitive with other disciplines and attract the brightest minds in the country and the rest of the world. Participants at the conference reported that recruiting increasingly requires more personal faculty attention to students, and cannot be left to administrators. It is increasingly important to advertise the specific features of a graduate program that can make the program attractive to prospective students, and to consider how well the interests and plans of the students are matched with the features of the program.

Flexibility in the graduate program and good metrics of student progress and potential are essential to ensure the success of a diverse group of graduate students. Some departments have instituted a holistic approach to admissions and retention, including a balanced look at indicators typically gathered for admissions, but without specific cutoff figures. The GRE in particular has proven problematic for departments seeking to increase diversity. Using a cutoff score for the GRE is specifically discouraged by the Education Testing Service (ETS), the makers of the exam, as GRE scores are not a measure of research success potential, but an indicator of preparation. Data indicate that while positive results on standard exams are somewhat predictive of performance on first year courses, the converse is not true for negative results: students who score poorly can still do well[9]. We note that similar observations helped lead the NSF to stop requiring the GRE for their prestigious Graduate Research Fellowships[10].

Presentations at the conference further bolstered the need for alternate admissions criteria. University of California at Berkeley faculty reported an unpublished study investigating potential correlations between incoming graduate students' admissions data (e.g. physics GRE scores, undergraduate GPA, etc.) and their assessed research excellence as professionals after graduating with a PhD. *They found no significant correlation between research success and any quantitative admissions-related measure*[11,12]. A poster presentation from the University of South Florida reported results of a similar study of their students, who had a much wider range of GRE scores[13]. Again, no correlation was found between quantitative or physics GRE scores and faculty ratings of the students' research ability. Since women and underrepresented students score lower on the GRE on average, relying heavily on such measures will likely reduce the diversity of a program, without fostering improvement in



research success. More research is needed on this topic, and APS should consider a more organized approach to collecting the data needed to understand these issues.

Departments should also refrain from rank ordering all of the applicants, attempting to "pick the best." Instead, departments should consider different "types" of students the graduate program needs (e.g., theorists, computational scientists, experimentalists, cross-disciplinary, etc.) and then deliberately select students that fill the various cells in that matrix.

Create cohorts and bridge programs to promote diversity

Departments can also promote diversity by facilitating community among graduate students. For some departments, it may be effective to construct diverse cohorts, with attention to a "critical mass" of underrepresented students, since cohorts can prevent isolation and provide students an opportunity to support each other. However, it is not realistic for every program to do this, since currently only about 500 minority students per year obtain bachelor's degrees in physics in the U.S., out of a total of about 5,800 physics majors who are U.S. citizens or permanent residents. To reduce feelings of isolation and build community, departments can plan events to connect students with campus groups, or encourage the formation of a graduate student club or social committee. Some departments reported that instituting defined times and places for core course study groups helps to integrate all students regardless of race, gender, ethnicity, or national origin. For example, departments could designate Monday at 7pm in Room X as E&M study time.

Programs such as the Fisk-Vanderbilt Masters-to-PhD Bridge Program[14] or the Columbia University[15] or University of Michigan[16] bridge programs can serve as good models for promoting diversity. APS recently launched an NSF-supported national effort to build bridge programs and explore effective strategies for promoting diversity in physics graduate education[2].

Adopt an exam structure that is effective and fair

In the 2006 Joint Task Force Report[3], the overwhelming majority of departments reported that they require a classical comprehensive style exam that was at least partly based on material from graduate courses. The informal impression at the 2013 conference was that this was no longer true. Some departments reportedly have shifted to different exam types. A number of departments have removed the time constraints in their exams in response to reports that timed exams may discriminate unfairly against women and minorities. In addition to an APS survey currently in progress on graduate admissions practices, participants felt it may be useful to conduct another survey about the exam structures currently used, and about the experiences of departments that have changed their exam structure since the last survey. In general, any exam structure should be aligned with departmental goals. The exams should be well matched with course preparation, and passing the exams should represent the minimum standard of competence expected in the program.

Provide social/cultural resources and support for graduate students

During their time in a graduate program, students will inevitably face many professional and personal challenges. A welcoming and helpful climate is crucial for overcoming these challenges successfully. Departments should take responsibility for establishing supportive relationships with graduate students as soon as they arrive on campus. This should be the responsibility of graduate student advisors, department chairs, other faculty, and graduate student groups. In every case, both graduate students and mentors should have a clear idea of a timetable and milestones for completion of the degree. Setting expectations as soon as possible can pave the way to success in the graduate program.

Participants agreed that the graduate program advisor is essential to establishing an environment of trust and respect among students and between students and faculty. Students should have the opportunity to make an informed decision when selecting a research mentor. Students' advisors and mentoring committees should initiate discussions with students about progress through the graduate program and career options. Excellent researchers are not automatically excellent advisors or mentors, and departments should consider sending all new faculty to the APS/AAPT/AAS New Faculty Workshop[20], or providing a 2-3 day professional development class for new faculty, with emphasis on time-management skills, mentoring[4], providing advice, respecting diversity, addressing personal as well as intellectual problems, and related issues; regular refreshers for all faculty members on these issues are highly recommended. Complaints of advisor-student abuse should be handled independently using a clearly defined local process that is well understood by students and faculty, rather than vertically through a specific chain of department and university officials. Departments should find a way to facilitate a change of advisors if necessary. It was suggested that departments consider taking interpersonal skills into account when hiring faculty.

Student peer "bonding" should be encouraged through common study areas, social activities, and student organizations. Students should be encouraged to seek peer advising and talk to other students about selecting an advisor, and faculty should give particular attention to students who appear too shy or isolated to benefit from their peers.

Departments should create family-friendly policies for graduate students. Universities should provide work-life balance benefits for students, including affordable family housing, parental leave, and child care. Departments should make information about such policies easily accessible to all graduate students via Web resources. Universities should set up a committee that includes students to work on the development and implementation of policies relevant to graduate students.

Graduate students should be encouraged to take advantage of the professional development opportunities available at their universities, since these skills are critical to success in any career. Department chairs should remind graduate thesis advisors that it is important for graduate students to develop professional skills while working on their PhD theses, rather than focus exclusively on research.

Mental health issues can be of great concern to some graduate students. Departments should make information about universities' mental health support resources easily available to graduate students and their families, as well as to all mentors and advisors. Graduate student advisors or mentors should not consider themselves to be experts on these issues, and should advise a student who needs help to take advantage of appropriate resources. Departments should refer students with mental health issues to professionals as soon as problems are detected, to prevent problems from escalating.

Mentor and Monitor Student Progress

Quite often the terms "advisor" and "mentor" are used interchangeably. Although an advisor can and should also serve as a mentor, many students need additional advice and guidance, especially when their thesis advisors are unable to provide appropriate support. Most importantly, departments must ensure students get help before a problem becomes unsolvable. Many departments report that they are already instituting formal mentoring programs, some based upon the mentoring resources that APS has on its website[4]. Departments should consider whether to require faculty members to take mentor training. Mentoring activities could also be added to the annual faculty review process. In the Massachusetts Institute of Technology (MIT) mentoring program[15], students have access to a range of faculty and peer mentors who possess a range of different backgrounds, knowledge, and experience. Participants suggested that the APS could encourage its units (e.g., divisions, topical groups, or sections) to establish mentoring awards, such as the one the Division of Nuclear Physics established in 2008[19]. Departments should also consider establishing such awards. It was recommended that mentoring and advising of graduate students be included in future APS/AAPT/AAS New Faculty Workshops[20].

Departments should have an explicit department-wide mentoring/progress monitoring plan that helps students from a variety of backgrounds thrive in the graduate program. One such plan discussed at the conference involved having a mentoring committee consisting of three faculty members, including the thesis advisor, for each student. This committee meets yearly, although a student could meet with the mentor of his or her choice at any time throughout the year for confidential advice. Committee members provide written feedback on students' progress on their research topic, as well as on their oral and written communication and other professional skills. In order to ensure that faculty members understand their critical role as mentors, departments may require that the yearly

self-evaluation by each faculty member include not only a bulleted list of graduate students advised but also explicit information about the faculty member's graduate student mentoring. MIT reported that they have implemented such a policy.

Add flexibility to the graduate curriculum

What constitutes a "core curriculum" and what defines a "physicist" remain challenging questions for physics departments. Conference participants agreed that everybody with a PhD in physics should be expert in understanding and applying the core upper-level undergraduate physics curriculum: quantum mechanics, electricity and magnetism, classical mechanics, and statistical mechanics. However, the increasing number of interdisciplinary programs in which physics graduate students participate require that departments offer more flexibility than in the past. Each department must decide what graduate courses are necessary to enable its students to have a successful career as a physicist. While some departments may pride themselves on offering a standard, traditional set of core physics courses, others could offer a more compressed core that would be attractive to students with broader interdisciplinary interests. In any case, each program must base these decisions on its overall goals.

Departments may also want to consider creating more flexible curricula that allow graduate students to take advantage of interdisciplinary and multi-disciplinary research at their universities. Departments should explicitly contemplate and pay careful attention to those student outcomes considered to be a "success." Too much rigidity in defining academic success may be detrimental to promoting intellectual diversity in graduate education in physics, and may cost a department the potential that physics offers. For instance, it has been found in studies done by some departments that the ability to complete the introductory courses is not a measure of competence or innovation in research[11]. The Applied Physics program at the University of Michigan reported the success of a flexible curriculum that converts the diverse needs of its students into successful graduates[17].

Focus on career development and professional training

The success of a graduate student is not guaranteed with the passing of the core courses or a comprehensive exam. Physics graduate school should prepare students for a successful career in which they apply the knowledge and skills gained during their studies and research. In addition to mastering a broad physics background, students should be given the opportunity to learn and perform the many aspects of independent research as well as to become proficient in professional skills.

Departments should have a department-wide plan to ensure that graduate students have sufficient opportunity to develop professional skills such as oral and written communication, teamwork, leadership and management, and mentoring. Success in both non-academic and academic careers depends strongly on these professional skills, and a good place to assess development of these skills is in the student's annual thesis progress review. University administration, including departmental leaders, should provide frequent verbal and written support for professional training of graduate students. Leadership at this level will help to develop a culture that recognizes the importance of professional skills. Departments should ask external reviewers to include professional skills training in their assessment of the department.

Mechanisms should be put in place to ensure that all graduate students have the opportunity to develop these skills regardless of their thesis advisor's involvement. A good example of resources to help students is available through Reference 21. TA training courses can be helpful in this regard. Universities should provide actual courses or seminars instead of "check-the-box" exercises for training in topics such as ethics and diversity. Departments may consider partnering with other parts of the university (e.g. liberal arts departments, business school, or engineering programs) in order to develop programming for helping graduate students with written and oral communication skills, ethics training, management skills, intellectual property, and other topics of interest. Certificate programs can be useful ways to obtain broader training; for example, some universities offer a certificate in education for those who wish to obtain

additional teaching skills. Oral communications training and presentation skills can be honed by using video capture and associated critiques by faculty and peers. Departments should also broaden the programming of colloquia to include former physics graduate students who are not in academia, and they should encourage current graduate students to interact with these alumni in order to learn firsthand that professional skills are critically important to their future success.

Prepare students for diverse careers

According to AIP[1] and NSF[22] data, the percentage of PhD physicists in industrial careers has steadily increased. Currently, only about 20% of physics PhD graduates take faculty positions in colleges and universities, while about 55% are employed in industry. However, most physics graduate programs do not prepare students well for a career outside academia, presumably because professors are poorly informed about non-academic careers. To address this shortcoming, faculty should educate themselves and advise students about careers outside of academia, and provide specific and integrated training in broadly valued skills such as communication, time and project management, and leadership. Departments should invite seminar or colloquium speakers from local industries or from their alumni who work in industry, and ensure that speakers have ample time to interact with students during their visit. Mock interviews for graduate students preparing for non-academic careers can be very effective in making sure that students emphasize broad process skills that may be relevant to non-academic careers, rather than discussing the technical details of their graduate research. In addition, departments might consider strategies for providing limited-term internships to graduate students in an industrial or government lab that is not necessarily related to their thesis research. It may be helpful not to use the term "alternative career," as this may imply such careers are inferior to a career in academia.

This conference mostly focused on non-academic careers in industry and in national laboratories. These and other non-academic career paths are discussed on the APS careers web site[23].

Conference participants identified a set of intertwined and complementary professional skills, described below, that are crucial to success in non-academic careers. While it was evident that graduate school prepares students well to perform independent basic research, it was equally evident that most graduate schools do not intentionally prepare students for the non-academic careers that most of them will have.

Expert learning and innovation skills

Graduate students entering the 21st century job market must exhibit intellectual agility, so that they can rapidly learn new fields and apply their existing knowledge to new situations, including those with an applied or engineering focus and projects with specific goals, budgets, and schedules. Physics graduates should be trained to be problem solvers who can use their deep core knowledge of physics to dive deeply into a particular area, lead projects in this area by engineering solutions based on their physics knowledge, and communicate successfully with technical and non-technical team members.

Key Findings & Recommendations

Success in industry also requires that graduate students learn to embrace innovation. This involves using deep knowledge of physics concepts to solve well-defined as well as ill-defined problems that may have pre-defined or ill-defined design constraints. Physicists must be able to take early concepts and prototypes and increase their technological readiness or usefulness. Conference participants recommended that students be exposed to toolsets used in industry, particularly software packages with a physics and laboratory focus. Statistics and programming were also mentioned as important skills. Students should be encouraged to demonstrate that they can successfully accomplish tasks outside the "box" of standard academic research and develop skills in leadership, initiative, communication, intellectual property, planning, budgeting, and teamwork.

Leadership

Leadership skills useful in industry include conceptualizing and planning projects; performing prototyping, simulation, and modeling; testing, documenting, and reporting; and program management skills like scheduling, budgeting, and executing a plan by delegating work to team members and coordinating with others. A leader should be able to focus his or her team on reaching its goals, while keeping all team members and stakeholders informed of progress and problems. Graduate students can develop leadership, team building, and collaboration skills early in their graduate careers in study groups and while collaborating with their peers and other groups in their research programs. Later in their graduate career, students can practice their skills while they perform their thesis research. Mentoring is also an important skill in many careers, as senior team members must frequently provide on-the-job training to junior members. Beginning this training at the graduate level by having senior level graduate students mentor entry level graduate students, and undergraduates is recommended.

Project Management

Most industrial physicists manage projects, which includes defining scope, setting a schedule that includes realistic deliverables, and developing and following a budget. Graduate students should develop these skills. One natural way to develop these skills is to use the graduate student's thesis research as the project he or she is managing. By setting goals, developing a schedule, and working with their professor or financial representative to set up and monitor their group's budget, a graduate student can begin to develop these skills. This requires only a slight modification of the path that most graduate students already follow. Students can also take a program or project management class taught in a business school. Alternatively, departments can generate their own classes, as was done in The Art of Science course at the Center for Graduate Education at the Colorado School of Mines[24]. *The Art of Being a Scientist: A Guide for Graduate Students and Their Mentors* by Roel Snieder and Ken Larner[25] is a useful resource for this and other professional skills.

Communication skills

Physicists must be able to communicate both verbally and in writing for diverse audiences, including co-workers, technical experts, technicians, program managers, upper management, funding sources, and the public. They must be able to effectively communicate to foster a common sense of purpose among team members. Many participants from industry and national labs pointed out the need to be able to give an "elevator speech"—in other words, to describe a project, its importance, and its goals to a non-expert in 30 seconds. While students often work for long stretches of time before writing a paper, in industry they must be able to provide progress reports on a regular basis, often monthly or quarterly. Students need to learn how to concisely communicate to their diverse audiences both verbally and in writing, using appropriate tables and graphs. Graduate students can hone these skills by giving succinct and regular updates of their thesis progress to their research advisors, fellow graduate students and research group members, and thesis committee.

Interpersonal skills

Interpersonal skills are critical in all career paths. Many conference participants pointed out that professors and mentors serve as role models in their treatment of graduate students. Research advisors must thus model the behaviors that will be critical to the success of their students in their future careers. Students should learn to work on a team, develop good listening skills, and value suggestions and feedback from their peers, technicians, and professors. Industry relies on cross-functional teams that include scientists and engineers from different disciplines, program managers, as well as financial, contractual, and quality representatives. Students must learn

to lead or manage such teams, and to participate as productive team members. They can practice this in the latter stages of their thesis work by leading a team that includes early-stage graduate students and others. Scientists must also interact with their customers, who could be internal or external sponsors of their work. Coaching graduate students on how to interact with NSF or other funding source program officers would therefore be a beneficial experience.

Proposal Writing

Finding funding opportunities, understanding funding requirements, and writing proposals to satisfy these requirements are a part of nearly every career. Physicists in both industry and academia will likely write proposals to external funding sources. Alternatively, industrial physicists often write a proposal to their managers, requesting funding for a self-generated project idea. Students should develop the planning, research, and writing skills needed to generate proposals of either type. This can be accomplished by ensuring that graduate students receive opportunities to draft proposal components and receive feedback on their writing early in their graduate careers, and then take a leadership role in writing proposals or proposal components late in their graduate careers.

Industrial Research Experiences and Connections

Based on statistics from NSF, AIP, and other sources, only about 20% of PhD physicists become professors at two-year, four-year, and graduate-degree granting universities. This fact is not well known, which may result in the large percentage of graduate students who aspire to become physics professors. Students should be informed as early as possible about these statistics, and about all available options for physics careers, including positions at national laboratories, industry, and other private-sector jobs. University career services are a good resource. Other resources include former students of the advisor, other alumni of the department, career fairs at APS meetings, and professional, industrial, and engineering conferences.

There was a clear consensus among conference participants that physics departments need to explicitly and implicitly value a broad range of career paths[23] as being appropriate for their graduates. Professors should not be assessed more positively if a higher number or percentage of their former graduate students obtain careers in academia. This should apply to both external evaluations by granting agencies as well as internal evaluations by departments. Linkages with industry can be beneficial to physics departments by providing research collaborations, graduate student internships, and potential funding for department activities. These linkages can be made via personal contact or via administrator's initiatives from either the industrial side or the academic side.

While physicists have deep knowledge of the physics that underlies many technologies, many professors and graduate students have no experience working with engineers to create real products. To address this, applications and engineering aspects of the material covered in selected graduate courses can be added to a department's curriculum. Professors from business schools or departments can be invited to give colloquia or seminars about technical program management. Students can be exposed to business methods and non-academic careers in internships and co-ops. In the engineering world, graduate students often complete internships at industries or federal labs; however, this is not common in the physics community. This is a barrier for students to get an early glimpse into non-academic physics career options. Departments should actively seek out opportunities for their students to interact with industry and other non-university employment opportunities. Some departments, such as the University of South Florida, require graduate internships, even though half of their students proceed to postdoctoral positions rather than industrial ones.

Physics department should follow their alumni and perform alumni surveys. These surveys would provide information about physics careers. Surveys are useful tools for graduate program assessment, since they can reveal those skills that alumni use to be successful in their jobs. Graduate programs can then determine how such skills could be taught to graduate students. Social networking tools like LinkedIn are other ways to communicate with alumni. Departments may find it beneficial to reach out to alumni as well as physicists and engineers in local industries and invite them to interact and speak to their students at, for example, colloquia, or job fairs.

Graduate students who apply to non-academic jobs need advice to adjust their résumés to reflect what they can do, in addition to what they have done. When writing letters of recommendation, professors should also emphasize what students can do. Students will be hired if they have skills that are applicable to the challenges faced by their potential employer, and if they demonstrate that they have the ability to solve complex problems.

Departments may consider starting professional masters programs in physics to cater to various types of jobs, and creating mechanisms to provide financial support to students who choose this track. The Colorado School of Mines provides half tuition and TA support to professional masters students.

APS has many resources related to non-academic careers, and holds regular workshops and job fairs at its national meetings. Also, AIP[1] has many statistics relevant to industrial careers on their website. Though the APS careers website[25] currently features a number of videos from webinar broadcasts featuring industrial physicists, it should also include some shorter, interview-style videos as well (similar to career videos at the IEEE website[26]). A recent *Physics Today* article about entrepreneurship's role in physics education is another excellent reference[27].

Incorporate Feedback from Alumni to Improve Graduate Program

Departments should track the placement of their PhD[1] students over time and periodically solicit feedback from them in order to improve their graduate programs and make them more relevant to students entering the current job market. Currently such tracking is piecemeal, with some faculty members doing an excellent job, and others failing to do so. AIP tracks such data on a national scale[1]; thus, the comparison of a department's data with AIP data can be helpful in determining strengths and weaknesses. Graduate students can be encouraged to join networks of professionals, for example on LinkedIn, which, because of its independence from any particular email address or contact information, can help with long-term tracking and feedback from alumni. Departments should conduct exit interviews with graduate students who succeed in obtaining their PhD, as well as those who do not.

Summary & Next Steps

The 2013 Graduate Education in Physics Conference made clear that since the 2006 Task Force Report[5] and the last Physics Graduate Education Conference in 2008[6], significant changes in many aspects of graduate education in physics have already occurred in some departments, for example in the area of exams and in diversity programs. This report has recommended additional changes, for example in advising and better preparing students for careers. It is time to collect data related to these changes and to analyze and evaluate the progress made toward addressing 21st Century challenges. The APS Committee on Education is currently discussing how to gather appropriate data that would help inform graduate programs and provide guidance for departments wishing to improve their programs. The APS Bridge Program is also carrying out a number of studies on graduate admissions practices that promise to provide a comprehensive perspective on how departments make admissions decisions. The results of these efforts should begin to appear in 2014.

When the results are available, they will be discussed at the next conference on graduate education in physics, anticipated to be held in 2018. The participants of the 2013 conference rated the meeting as extremely useful and strongly suggested such a follow-up conference.

References

1 AIP Statistical Research Center. *www.aip.org/statistics*

2 APS Bridge Program. *www.apsbridgeprogram.org*

3 PER Central. *www.compadre.org/per/*

4 APS Physics Mentor Research Training. *www.aps.org/programs/education/undergrad/faculty/mentor-training.cfm*

5 The report of the Joint AAPT-APS Task Force on Graduate Education in Physics. *www.aps.org/programs/education/upload/2006_Grad_Ed_Report.pdf*

6 Graduate Education in Physics. Which Way Forward? *www.aps.org/programs/education/graduate/upload/2008-APS-Graduate-Education-Conference-Report_v0213.pdf*

7 IPEDS Completion Survey by Race. *nces.ed.gov/ipeds/resource/*

8 United States Census. *www.census.gov/*

9 B. Bridgeman et al. "Understanding What the Numbers Mean: A Straightforward Approach to GRE Predictive Validity." Educational Testing Service. September 2008. *www.ets.org/Media/Research/pdf/RR-08-46.pdf*

10 Personal communication, NSF program officers.

11 Building Successful Graduates: Definitions, Admissions, Retention (Session Notes from 2013 Graduate Education Conference). *www.aps.org/programs/education/graduate/conf2013/upload/Scribe-Notes-Panel-Session-II.pdf*

12 Personal communication, Frances Hellman

13 C. W. Miller. "Admissions Criteria and Diversity In Graduate School." APS News, February 2013. *www.aps.org/publications/apsnews/201302/backpage.cfm*

14 Fisk-Vanderbilt Masters-to-PhD Bridge Program. *www.vanderbilt.edu/gradschool/bridge/*

15 Bridge to Ph.D. Program in the Natural Sciences. *academicplanning.columbia.edu/bridge-phd-program-natural-sciences*

16 Imes-Moore Fellows Program. *applied.physics.lsa.umich.edu/imes_moore.html*

17 University of Michigan Applied Physics program. *www-applied.physics.lsa.umich.edu/*

18 MIT Physics Resources for Easing Friction and Stress. *web.mit.edu/physics/refs/*

19 APS Division of Nuclear Physics Mentoring Award. *www.aps.org/units/dnp/awards/mentoring.cfm*

20 New Faculty Workshops. *www.aapt.org/Conferences/newfaculty/nfw.cfm*

21 Center for Professional Education, Colorado School of Mines. *cpe.mines.edu/*

22 Survey of Earned Doctorates, National Science Foundation. *www.nsf.gov/statistics/srvydoctorates/*

23 Careers in Physics. American Physical Society. *www.aps.org/careers/*

24 Courses, Center for Professional Education, Colorado School of Mines. *cpe.mines.edu/Courses*

25 Appendix B. A sample curriculum from R. Snieder and K. Larner. The art of being a scientist. Cambridge University Press, 2009. *inside.mines.edu/~rsnieder/Art_of_Science curriculum.pdf*

26 Engineering and Technology Jobs, IEEE. *careers.ieee.org/*

27 "Things your adviser never told you: Entrepreneurship's role in physics education" by Douglas Arion, Physics Today, August 2013, p. 42-47

Appendices

Appendix I

Statistics related to physics graduate education

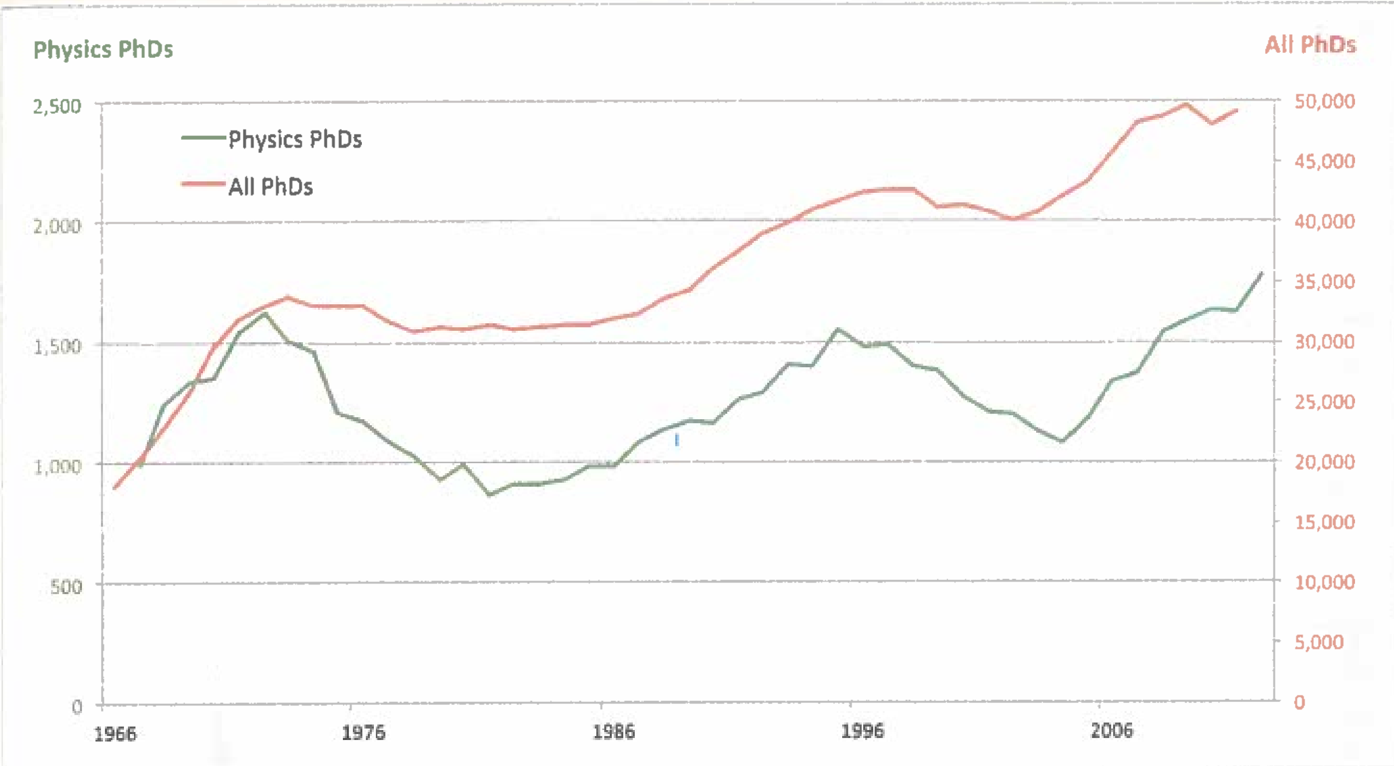


Figure 1. Physics PhDs and all PhDs conferred in the US. Source: NSF Survey of Earned Doctorates.

This appendix presents statistics relevant to graduate education in physics. Data were taken from AIP Statistical Research Center[1], NSF[2], Department of Education data sources[3], and US Census data[4]. The number of physics PhDs along with the total number of PhDs conferred in the US from 1966-2011 is shown in Figure 1, and the number of first-year, full-time physics graduate students from 1977-2011 is shown in Figure 2. Figure 3 shows that, over the last decade, the numbers of physics PhD degrees awarded to US citizens and non-US citizens has become comparable. Figure 1 also shows that the total number of Physics PhDs awarded in the last few years has been increasing steadily. This number exceeded 1700 for the class of 2011.

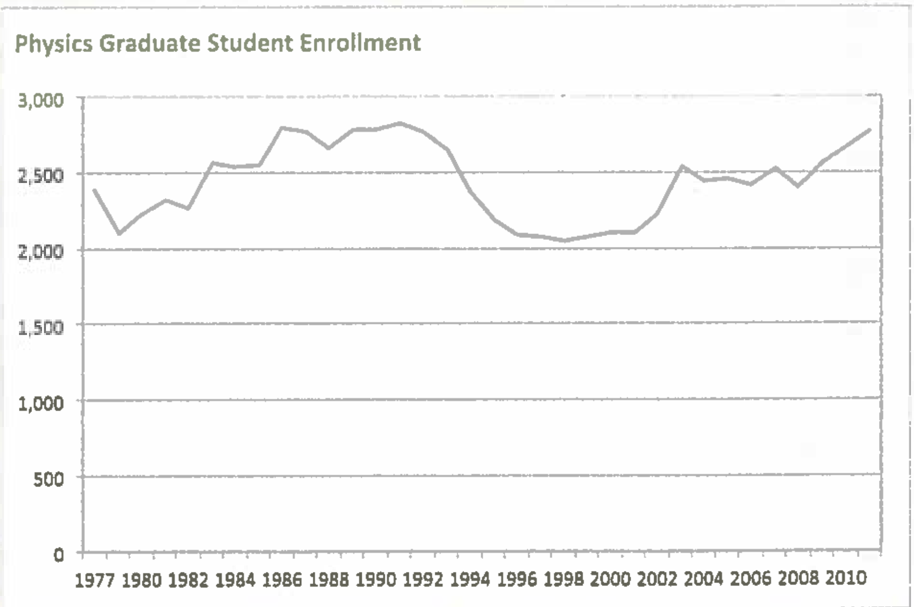


Figure 2. First-time, full-time graduate physics student enrollments at PhD-granting physics departments. Source: NSF-NIH Survey of Graduate Students & Postdoctorates in Science and Engineering.

Appendix I: Statistics Related to Physics Graduate Education

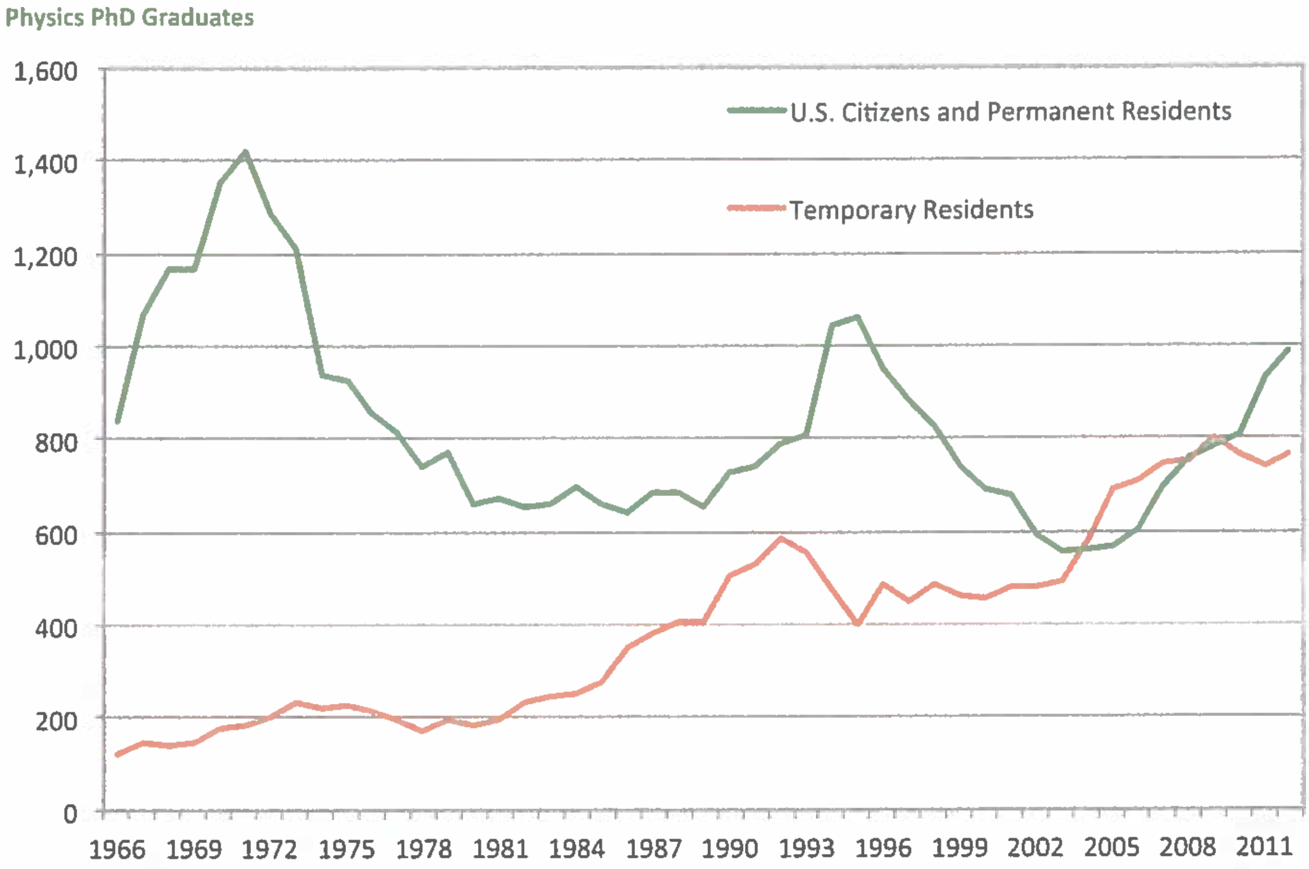


Figure 3. Citizenship of physics PhDs. Source: IPEDS Completion Survey (2007 to 2012) and NSF Survey of Earned Doctorates (1966 to 2006).

	Bachelor's		Master's		PhD	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
White	*4044*	*76.5%*	*147*	*84%*	*628*	*74.7%*
Asian-American	*360*	*6.8%*	*9*	*5%*	*59*	*7.0%*
African-American	*275*	*5.2%*	*9*	*5%*	*31*	*3.7%*
Hispanic-American	*157*	*3.0%*	*8*	*5%*	*15*	*1.8%*
Other US citizens or permanent residents	*452*	*8.5%*	*2*	*1%*	*108*	*12.8%*
Total US Citizens	*5288*	*100%*	*175*	*100%*	*841*	*100%*

Table 1: Source: Department of Education IPEDS Completion Survey and AIP Statistical Research Center. Data represents three-year averages for 2009-2011. Based on exiting physics Master's degrees collected by the American Institute of Physics Statistical Research Center.

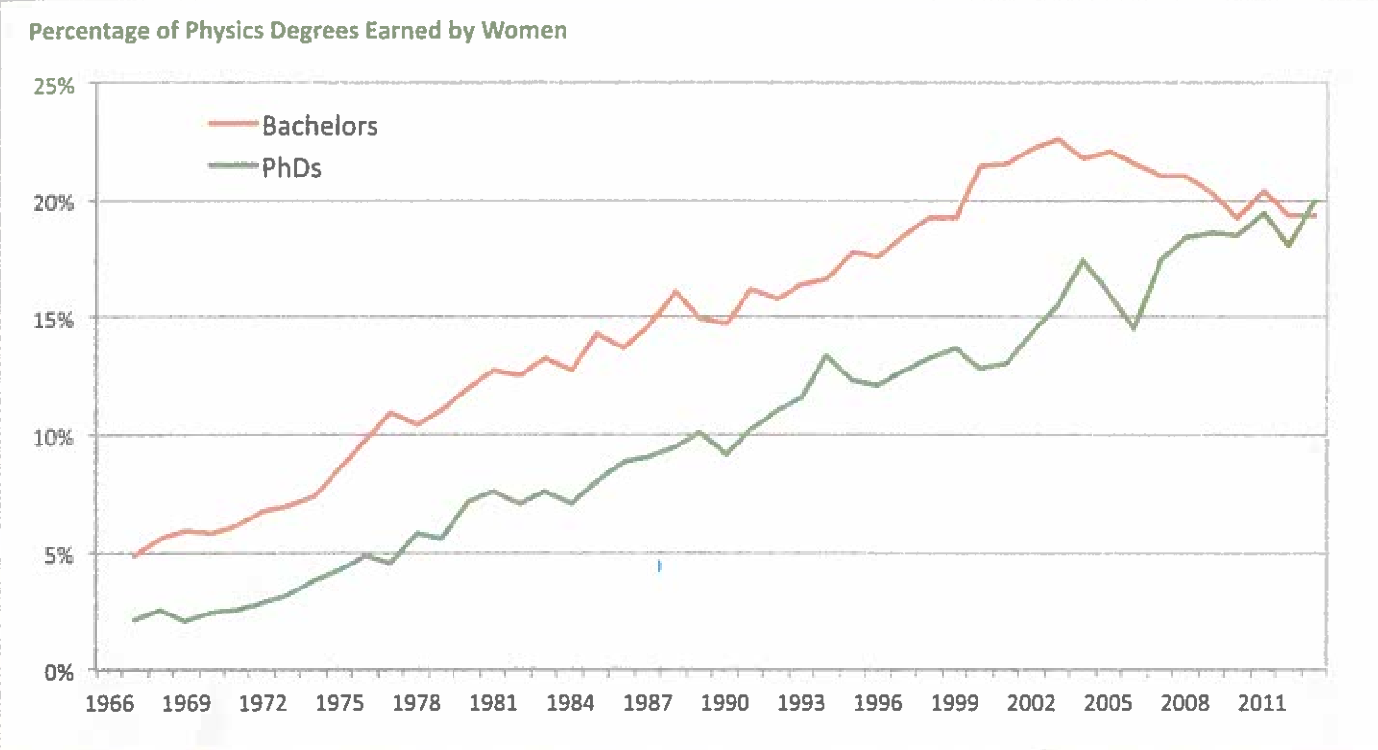


Figure 4. Fraction of Bachelor's and PhD degrees in physics earned by women. Source: Department of Education IPEDS Completion Survey.

Table 1 presents three-year averages of the racial and ethnic profile of physics Bachelor's, Master's and PhD classes of 2009 through 2011 for US citizens or permanent residents. These data show that the three-year average percentages of all US physics Bachelor's, Master's and PhD awardees who were African American and/or Hispanic American combined were 8%, 10% and 6%, respectively. Figure 4 indicates that women are also significantly underrepresented. Major demographic shifts in the US population, as shown in Figure 5, make it imperative that we identify successful ways to engage all population groups, and understand barriers that selectively impact specific groups. Understanding these barriers can help us improve education for all students.

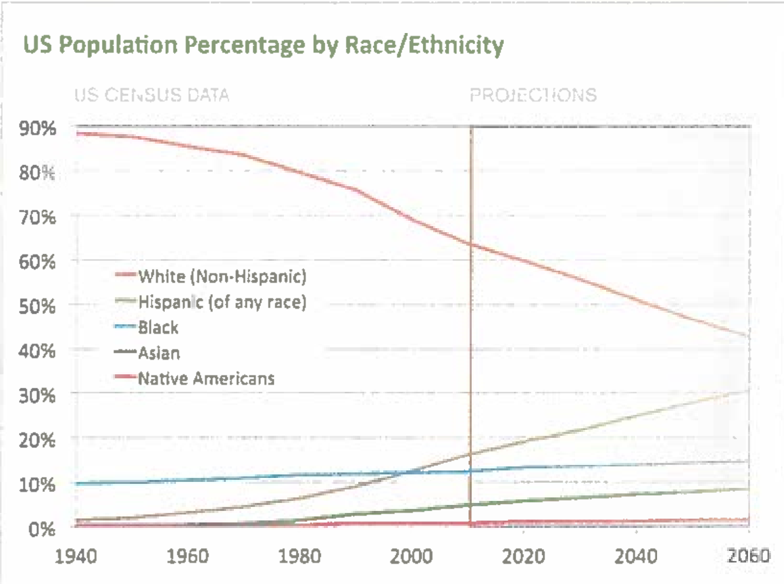


Figure 5. Demographic Shifts in the US Population. Source: US Census.

Appendix I: Statistics Related to Physics Graduate Education

	Highest Degree Awarded by Department	
	MS	*PhD*
Gender		
Male	77%	80%
Female	23%	20%
Citizenship		
US	64%	56%
Foreign	36%	44%
Median Age	25.2	23.5
Highest Degree Desired		
PhD	65%	90%
MS	18%	4%
Unsure	15%	5%
No Degree Intended	2%	1%
Enrollment Status		
Full-time	96%	98%
Part-time	4%	2%
N	180	2126

Table 2: Demographics of first-year physics graduate students by institution type, fall 2007 and fall 2009 combined. Source: AIP Statistical Research Center.

Table 2 presents the characteristics of first-year physics graduate students in the US by highest degree awarded by the departments from fall 2007 and fall 2009 combined. This table shows that 90% of all graduate students enrolled in PhD granting departments desired to earn a PhD and 20% of the first year physics graduate students in those PhD granting departments were women. The data also indicate that 98% of the graduate students in PhD granting departments were enrolled full-time.

Figure 6 is a histogram of the number of years of physics graduate study required to receive a physics PhD for the classes of 2010 and 2011 combined. This figure considers graduate study completed in the US and excludes PhDs who had previous study at a non-US institution. These data show that the average time to degree for a PhD is 6.2 years.

Figure 7 is a snapshot of the employment sectors of physics PhDs in 2001 classified by when they received their degrees. The data is disaggregated into 5-year cohorts based on the class in which the individual received their degree. At the time of the survey the physicists in the 1946-1965 cohort were older (in their 60's and 70's) where the 1996-2000 cohort were in their 30's[1]. The variations between the cohorts can reflect both the impact of the economic climate when the students received their degrees and also changing patterns that characterize careers as they

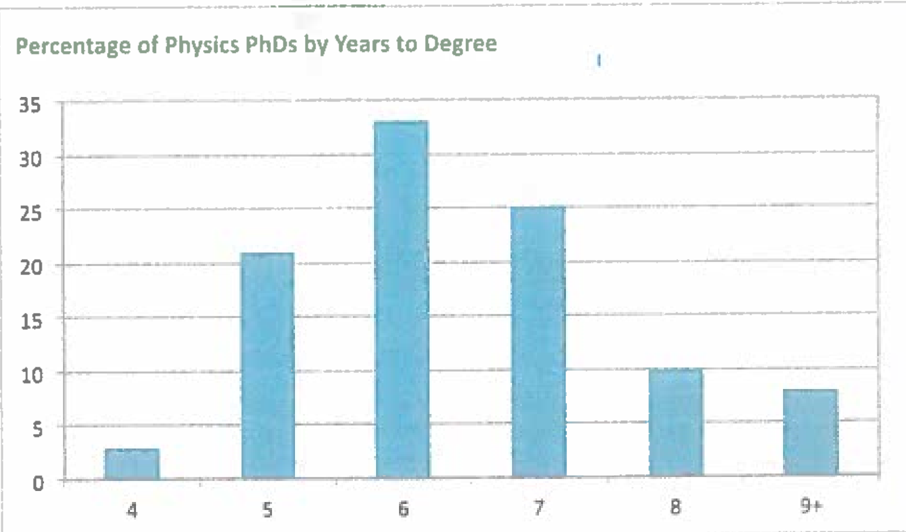


Figure 6. Years of physics graduate study to receive a PhD, classes of 2010 and 2011 combined. Source: AIP Statistical Research Center.

advance over time, including different retirement ages and post-retirement arrangements in different sectors. The oldest group may include individuals who have opted for a semi-retirement status. Individuals holding postdocs were excluded from the table. It is clear from the table that the private sector is a major employer of physics PhDs regardless of when the degree was awarded.

Figure 8 portrays the initial employment statistics for physics PhDs from 1979-2010. This figure shows that the number of physics PhDs who were unemployed remains quite low, generally less than 5%. Over the same period the percentage of PhDs who took up postdoctoral positions fluctuated between about 40% and 65%.

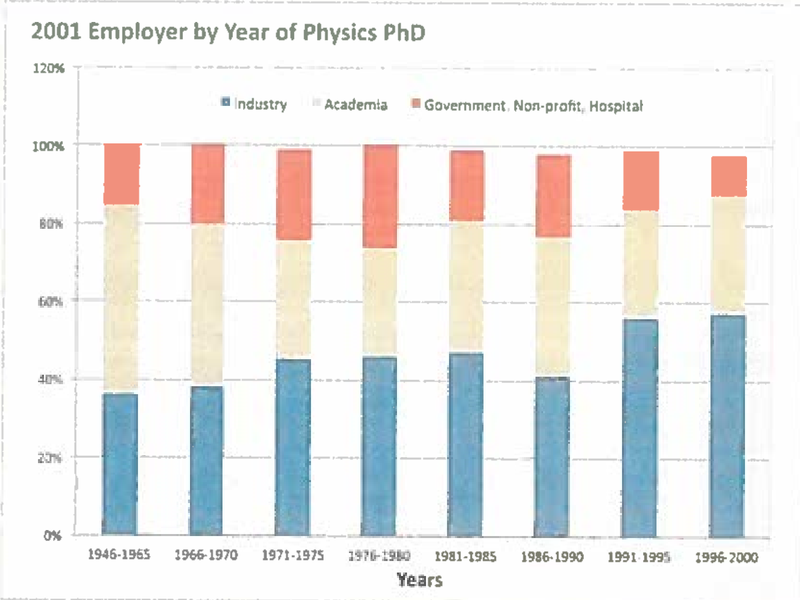


Figure 7: Career outcomes for PhD physicists in 2001 by year of physics PhD. Source: NSF Survey of Earned Doctorate Recipients, compiled by AIP Statistical Research Center.

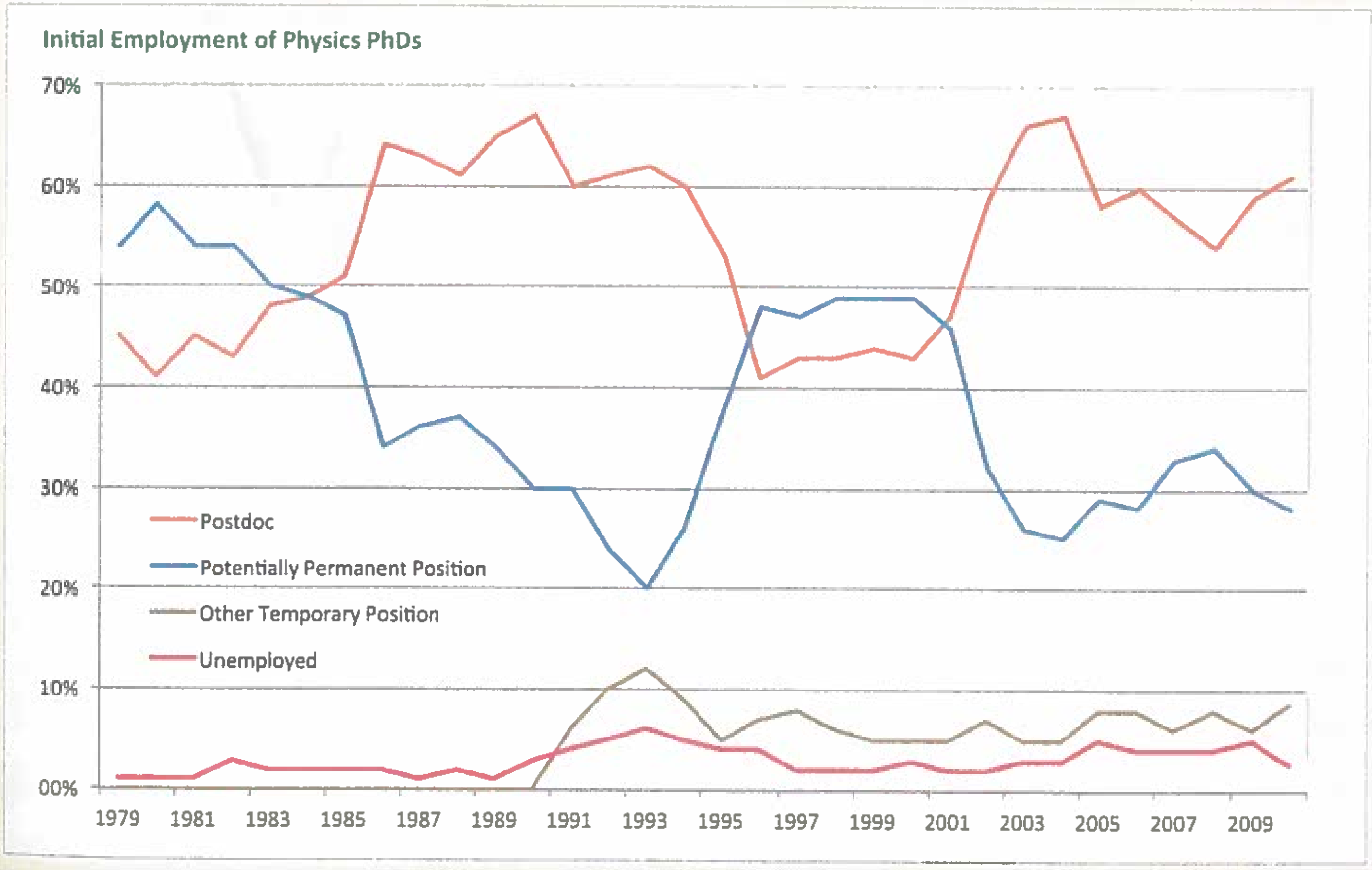


Figure 8. Initial employment of Physics PhDs in the US. Source: AIP Statistical Research Center. In 1991, the survey questionnaire was changed to measure "other temporary" employment as a separate category. Data only include US-educated PhDs who remained in the US after earning their degrees.

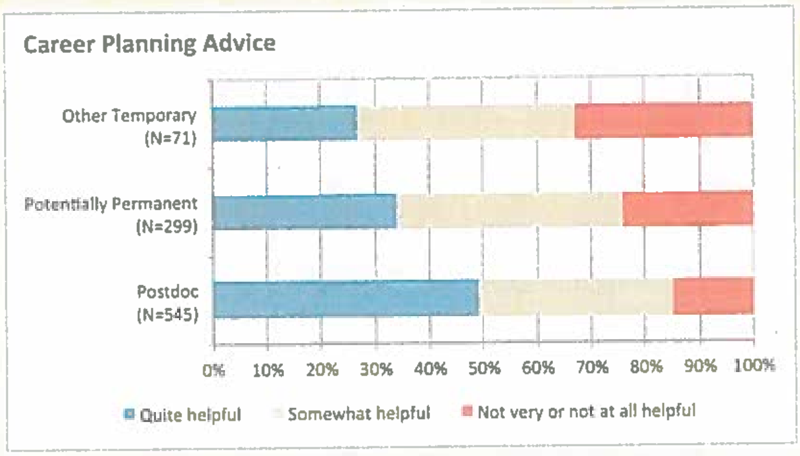


Figure 9. Physics PhD classes of 2009 and 2010 combined response for "Was your advisor helpful in your career planning?" Source: AIP Statistical Research Center. Data only include US-educated physics PhDs who remained in the US after earning their degrees. Data represent responses based on a 4-point scale.

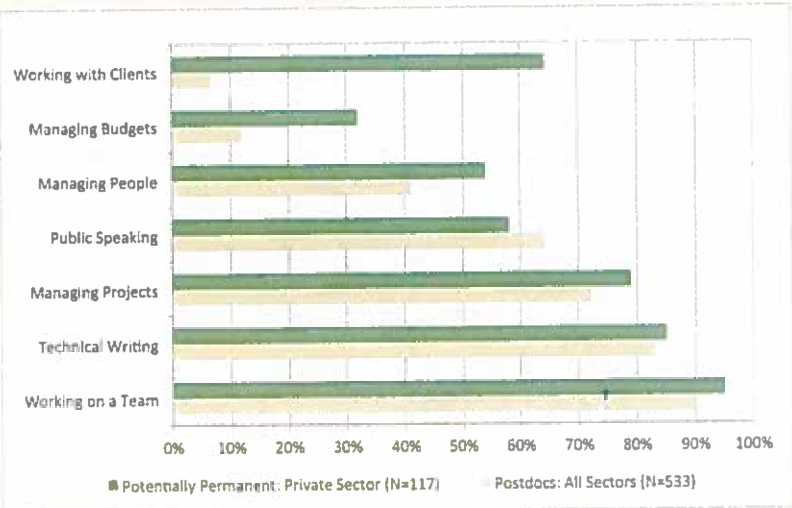


Figure 10. Interpersonal and management skills regularly used by new physics PhDs, classes of 2009 and 2010 combined. Source: AIP Statistical Research Center. Percentages represent the proportion of physics PhDs who chose "daily", "weekly" or "monthly" on a four-point scale that also included "never or rarely". Data only include US-educated physics PhDs who remained in the US after earning their degrees.

Figure 9 presents the combined responses of the physics PhD classes of 2009 and 2010 to the question: "Was your advisor helpful in your career planning?" Variations are evident depending on the eventual employment of the individual, most likely reflecting the degree to which advisors are familiar with the planned employment possibilities. This statistic reflects the importance of doctoral programs seeking advice from potential employers to help their students understand these career options.

Figure 10 shows that working on a team, technical writing, managing projects, public speaking, and managing people were skills regularly used by new physics PhDs. Graduate programs should give all graduate students an opportunity to develop these skills. Figure 10 also shows that managing budgets and working with clients were rated as important interpersonal and management skills mainly by those in potentially permanent positions in the private sector—skills not often addressed in graduate studies.

For additional information and further statistics, please visit References 1-4.

References:
1. AIP Statistical Research Center, *www.aip.org/statistics*
2. NSF Survey of Earned Doctorates, *www.nsf.gov/statistics/srvydoctorates/*
3. NSF and Department of Education Data Sources, *webcaspar.nsf.gov*
4. United States Census, *www.census.gov/*

Appendix II
Recommendations from the 2008 Conference

The full report from the 2008 Graduate Education in Physics Conference is available online[1].

Several important themes, relating to the curriculum and to the wider graduate experience, emerged from the conference. The recommendations, if adopted, should lead to an improved, more flexible, and more relevant graduate experience for all students.

The perception that a PhD is only for an academic career

Most graduate students receiving a PhD in physics do not enter a career in academia, and it should never be assumed that academia is the only goal. Physics departments should prepare students for other career options. The expectations for careers in academia and industry are very similar: a broad physics background, the proven ability for independent research, and effective communication skills. Thus the programs themselves do not have to be changed, but rather the perception that careers in areas other than academia are less desirable. In addition, career guidance is lacking.

Recommendations

Departments should:

- take pride in and support graduate students who aspire to non-academic professions.
- provide career guidance for graduate students that helps them prepare for a wide range of possible vocational options.

The APS should:

- adopt a statement that articulates the goals and purpose of the doctoral degree to emphasize to students, departments, and potential employers that the PhD represents a sound preparation for diverse careers.

A static curriculum

The core curriculum and the exam structure have been the topic of many recent meetings and discussions. The Joint AAPT-APS Task Force on Graduate Education in Physics summarized the present status of the core courses but did not investigate in detail the content taught in these courses. Anecdotal evidence points to static content and traditional texts that do not reflect the current state and practice of physics. The emergence of many interdisciplinary subfields requires new courses that may conflict with the traditional curriculum.

Recommendations

Departments should:

- consider broadening (not increasing) the core to encourage the interdisciplinary aspirations of students and faculty; and
- regularly examine the currency and relevance of topics taught within the core and in the wider curriculum.

Professional societies should:

- follow up on the AAPT-APS task force findings by gathering information about the content of the core courses.

Exam structure

There is currently no common exam structure followed by departments. Many institutions experiment with various combinations of written, oral, preliminary or comprehensive exams as well as final exams in the core courses. This topic is intensely debated among faculty. Do exams really assess readiness for a research degree?

Recommendations

Departments should:

- critically assess the desirability and efficacy of their comprehensive exams.

Professional Societies should:

- gather information about comprehensive and preliminary exams and make common practices known.

Need for guidance, mentoring, and professional development of graduate students

Graduate students are our young colleagues. Departments and individual advisors have the joint responsibility to guide and mentor the students to develop professionally during their graduate careers and to make a timely transition to the workforce.

Recommendations

Departments should:

- make mentoring and guidance of graduate students a priority that is appropriately rewarded.
- institute methodical tracking of graduate students and their progress towards the degree.
- adopt policies that reduce the time-to-PhD with particular emphasis on reducing the number of students that take longer than 6 years to graduate.
- encourage graduate students to participate in professional organizations to help them learn networking and other professional skills.

1 *www.aps.org/programs/education/graduate/upload/2008-APS-Graduate-Education-Conference-Report_v0213.pdf*

- encourage, though not require, student involvement in outreach activities as a positive aspect of the graduate experience. Professors should lead by example and encourage their students to participate.

Training for teaching assistants (TA)

All PhD-granting departments rely heavily on graduate students to assist in the delivery of undergraduate courses. Graduate students should be properly trained in pedagogy, content, and class management to enable them to effectively carry out this important role. Departments are also the training grounds for future faculty and must therefore model innovation and excellence in teaching, just as they do in research.

Recommendations

Departments should:

- develop effective TA training programs that pay attention to pedagogy and professional development.
- continue TA training and mentoring throughout the graduate teaching experience.
- provide "shadowing" teaching opportunities for students who aspire to faculty positions.

Ethics training

Departments have a responsibility to teach and uphold the strongest ethical standards. We must respect and acknowledge students' intellectual contributions and ensure that they are treated fairly, as colleagues. Ethical issues include honesty in the conduct and reporting of research, integrity in the setting and taking of exams and assignments, and matters relating to fair treatment of our co-workers.

Recommendations

Departments should:

- offer ethics training for students. More than one experience is needed to ensure that students revisit the topic as more mature researchers. Advisors should continue to model the highest ethical standards.
- ensure that ethics training addresses human and social issues like treatment of colleagues, stewardship of natural resources, integrity of funding sources, as well as the obvious issues of cheating, plagiarism, etc.
- develop a graduate student handbook that specifies the rights and responsibilities of students and faculty members.

Professional Societies should:

- conduct ethics workshops at national meetings and the AAPT/APS/AAS New Faculty Workshop.

Developing communication skills

Skills beyond technical expertise are increasingly important. Departments have a responsibility to teach students how to communicate effectively at all levels, and to develop the writing, speaking, presentation, and negotiating skills that will serve them in a complex work environment. Critical thinking and critical analysis of scientific information have long been the hallmark of the physicist, and the cultivation of these complementary skills must permeate all aspects of the graduate experience.

Recommendations

Departments should:

- require students to present their research orally in a public forum and provide opportunities to help them prepare and to provide them with feedback on their performance.
- require students to submit a written paper describing their research for peer review in an appropriate journal.
- encourage students to present their research at conferences, and provide financial assistance where possible.

Encouraging diversity and a supportive climate

Women and, to an even greater extent, minorities continue to be underrepresented in physics, particularly at the PhD level. It is essential for departments to focus on creating a climate that attracts and retains women and minorities in physics both as students and as faculty. Such a climate improves the environment for all students.

Recommendations

Departments should:

- implement best practices developed by the APS Committee on the Status of Women in Physics.
- consider bridge programs to help under-prepared students achieve success in graduate programs.
- develop written departmental plans for addressing issues of climate, image, recruiting, and retention of underrepresented groups.

Recruiting and retention of students

Many departments felt the need to improve recruiting. They cited poor statistics, particularly for women and minority recruitment, increasing competition from programs abroad, and competition from other disciplines.

Recommendations

Departments should:

- project an exciting, welcoming environment on their websites. The Director of Graduate Studies should be visible on the departmental website.
- network and recruit at special events for undergraduates at professional society meetings and other venues.
- work with administrators on campus to expand and improve recruitment.

Professional Societies should:

- explore the possibility of becoming or organizing a national clearinghouse for electronic graduate application materials.

- continue to provide events for undergraduates at its national and regional meetings where they can learn about the advantages of graduate programs in physics and meet with departmental representatives.

Funding agencies should:

- provide more fellowship support for graduate education in physics.
- funding agencies were also urged to consider instituting programs that provide support for individual faculty members or teams of faculty members who develop and evaluate new curricula for graduate students.

Next steps

The efforts of physics departments to improve graduate education will benefit greatly from a forum for continued discussions. Professional societies and funding agencies can provide support for such efforts.

Recommendations

Departments should:

- enhance the status of, and rewards for, faculty and staff who devote time and effort to improving the graduate experience.
- communicate their best practices to other departments and adapt the best practices of others to fit the local environment.

Professional Societies should:

- sponsor a conference for DGS every 3-5 years.
- implement a listserv for DGS.
- strengthen the relationship of physics departments with industry by organizing a high-level meeting to promote physics graduate students among industries.
- appoint a task force that examines and reports best practices in successful graduate programs. Such a task force would help disseminate practices presented in this document.

Funding agencies should:

- continue to support conferences, studies, and curriculum development and evaluation programs that enhance graduate education.

Appendix III
Acknowledgments

This report describes the results of the second conference on Graduate Education in Physics organized by the American Physical Society and the American Association of Physics Teachers. The conference received support from the National Science Foundation under Award PHY-1107258.

We would like to thank Kathleen McCloud, the NSF funding agency representative, for her advice and support. In addition, we wish to express our appreciation to the following American Physical Society (APS) staff members: Kate Kirby, Executive Officer; and Deanna Ratnikova, Women and Education Programs Administrator who generously contributed their time and skills. Their assistance was invaluable. We also thank Gabe Popkin, who proofread and provided editorial assistance, Patrick Mulvey with the American Institute of Physics Statistical Research Center, Kerry Johnson, APS Manager of Special Publications, and Krystal Ferguson, APS Graphic Designer.

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Appendix IV
2013 Conference Program

Thursday, January 31 (Marriott Greenbelt Hotel)	
7:00 – 10:00 pm	**Dinner** **Keynote Address:** **Some Thoughts on the Future of Graduate Education** *Meg Urry (Yale)* **Poster Session**

Friday, February 1 (American Center for Physics)	
7:15 am – 8:00 am	**Breakfast**
8:00 am – 9:00 am	**Interactive Plenary with Discussion: Promoting Diversity in Physics** *Anthony Johnson (UMBC)*
9:00 am – 10:15 am	**Panel session I: Preparation for Non-Academic Careers** *Zelda Gills (Lockheed Martin)* *Alex Panchula (First Solar)* *Kathy Prestridge (Los Alamos National Lab)* *Moderator: Larry Woolf (General Atomics Aeronautical Systems)*
10:15 am – 10:45 am	**Break**
10:45 am – 12:00 pm	**Breakout sessions I (parallel)** • **Non-Academic Careers** *Stefan Zollner (New Mexico State);* *Moderator: Larry Woolf (General Atomics Aeronautical Systems)* • **Improving the Graduate Curriculum; Multi/Inter-Disciplinary Courses** *Randy Kamien (Penn); Moderator: Michael Thoennessen (Michigan State)* • **General Professional Skills, Leadership/Team Building/Communication** *Roel Snieder (CO School of Mines); Moderator: Renee Diehl (Penn State)*

12:00 pm – 1:00 pm	**Lunch**
1:00 pm – 1:30 pm	**Discussion: Compiling Common Data on Admissions Decisions** *Discussion Leaders: Theodore Hodapp (APS) and Geoff Potvin (Clemson)*
1:30 pm – 2:45 pm	**Panel Session II: Preparation for Non-Academic Careers** **Building Successful Graduates: Definitions, Admissions, Retention** *Frances Hellman (UC Berkeley), Cagliyan Kurdak (Michigan), Andrea Palounek (Los Alamos National Lab); Moderator: Megan Comins (Cornell)*
2:45 pm – 3:15 pm	**Break**
3:15 pm – 4:30 pm	**Breakout Session I (parallel)** • **Exams/Exam Structure** *Michael Thoennessen (Michigan State)* • **Bridge Programs to Improve Diversity** *Marcel Agüeros (Columbia), Theodore Hodapp (APS)* • **Mentoring and Monitoring Student Progress** *Ed Bertschinger (MIT), Monica Plisch (APS); Moderator: Chandralekha Singh (Pittsburgh)*
4:30 pm – 5:30 pm	**Report-Out and Discussion**
5:30 pm – 6:00 pm	**Reception**
6:00 pm – 7:30 pm	**Dinner & Keynote Address: Reflections on Getting a PhD in Physics** *Cherry Murray (Harvard)*
7:30 pm – 9:30 pm	**Breakout Session II (Parallel)** **Roundtable discussions of compelling, unique, or perplexing ideas from your department** *(15 people each)*

Saturday, February 2 (Marriott Greenbelt Hotel)	
7:15 am – 8:00 am	**Breakfast**
8:00 am – 9:00 am	**Group Report-Out: Discussion from Friday Evening's Breakout**
9:00 am – 10:15 am	**Breakout Session III (parallel)** • **Vision for Graduate Education** *Cherry Murray (Harvard); Moderator: Chandralekha Singh (Pittsburgh)* • **University, Industry and National Lab Partnership for Graduate Education** *Mike Lopez (Sandia National Lab); Moderator: Steve Turley (Brigham Young)* • **Graduate Student Concerns** *Colin Campbell (Penn State), Cacey Stevens (Chicago); Moderator: Renee Diehl (Penn State)*
10:15 am – 10:45 am	**Break**
10:45 am – 12:00 pm	**Report-Out on Breakout** • **Conference wrap-up: steps forward, ongoing communication** • **Evaluation**
12:00 pm – 1:00 pm	**Lunch**

Appendix V
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Appendix VI
Pre-Conference Resources for the 2013 Conference

1. Executive summary of the 2008 Graduate Education in Physics Conference:
   www.aps.org/programs/education/graduate/conf2008/execsum.cfm

2. Top 10 actions from the study on research universities and the future of America:
   sites.nationalacademies.org/PGA/bhew/researchuniversities/PGA_069432

3. Forum on Education newsletter feature on preparing students for careers in industry:
   www.aps.org/units/fed/newsletters/fall2010/chair.cfm

4. Preparing physics graduate students for careers in industry:
   www.aps.org/programs/education/graduate/conf2013/upload/Preparing-physics-graduate-students-for-careers-in-industry.pdf

5. Article covering "Advancing Graduate Education in the Chemical Sciences":
   www.aps.org/programs/education/graduate/conf2013/upload/Chemistry-Ph-D-Programs-Need-New-Formula.pdf

6. ScienceCareers article on "Taken for Granted: Fitting the Job Market to a T":
   sciencecareers.sciencemag.org/career_magazine/previous_issues/articles/2008_09_05/caredit.a0800130

7. APS News Back Page on "Admissions Criteria and Diversity in Graduate School":
   www.aps.org/publications/apsnews/201302/backpage.cfm

8. Full report from the 2008 Graduate Education in Physics Conference:
   www.aps.org/programs/education/graduate/conf2008/resources/upload/gradedreport.pdf

9. Report of the AAPT-APS Task Force on Graduate Education in Physics:
   www.aps.org/programs/education/graduate/upload/Graduate-Education-in-Physics-Joint-APS-AAPT-Task-Force-Report.pdf

10. Educating the engineer of 2020: Adapting Engineering Education to the New Century:
    www.nap.edu/openbook.php?isbn=0309096499

11. Challenges in chemistry graduate education: *www.nap.edu/catalog.php?record_id=13407*

12. Full report on advancing graduate education in the chemical sciences:
    www.acs.org/content/dam/acsorg/about/governance/acs-presidential-graduate-education-commission-full-report.pdf

13. Physics research mentor training guide:
    www.aps.org/programs/education/undergrad/faculty/mentor-training.cfm

14. Tutorial on physics careers in industry and government:
    www.physics.oregonstate.edu/~tate/APS2010Tutorial/

15. Webinar on using modeling techniques to inform admissions policy:
    archive.constantcontact.com/fs007/1103000146788/archive/1110994606346.html

Appendix VII
Breakout Session Questions

Breakout Session I Questions

Non-Academic Careers

- Over the past five academic years, how many students received a traditional physics graduate degree (MS or PhD in physics) from your department. Think of their first place of employment. How many were (1) not employed for more than one year after graduation, (2) employed in academia (postdoc or permanent), (3) working for a federal/state/local government agency (postdoc or permanent), (4) working in the private sector?
- Now think about students who received a traditional physics graduate degree (MS or PhD) between 5 and 10 years ago. How many of them are (1) not employed, (2) employed in academia (postdoc or permanent), (3) working for a federal/state/local government agency (postdoc or permanent), (4) working in the private sector?
- Who in your department or university keeps track of this information?
- Now think about your graduates who work in non-academic jobs (not at universities or government research laboratories) and who left your department five or more years ago. Which skills learnt in your department do they find valuable? Describe the process you use to find the answer to this question.
- Who in your department has the skills that are considered valuable by your graduates in non-academic positions?
- How are these skills taught to your students? Are they taught to all students, only to those who intend to get non-academic positions, or not at all?
- Do you know of any model programs or practices that prepare students for non-academic careers? What are the strengths and features of these programs?

Improving the Graduate Curriculum; Multi/Inter-Disciplinary Courses

- Enumerate and delineate the various "tracks" or subbranches of our field.
- With time to degree always an issue, can we teach new courses without removing old courses?
- Which old courses could be compacted or removed and what does that mean for our identity as "physicists."
- Physics versus "Physics history."

General Professional Skills, Leadership/Team Building/Communication

- What general professional skills do physics graduates need to be successful in their career?
- What is the best way to teach these skills to student (e.g., separate classes, integrated in disciplinary class workshops, one-on-one contact with advisor, other?)
- Do faculty, in general, have these professional skills?
- How can we train advisors to optimally help students in th professional development?

Breakout Session II Questions

Exams/Exam Structure

- The report of the previous conference in 2008 included t following recommendation regarding exam structur There is currently no common exam structure followed departments. Many institutions experiment with vari combinations of written, oral, preliminary or comprehensi exams as well as final exams in the core courses. This to is intensely debated among faculty. Do exams really ass readiness for a research degree? Recommendations:
  - *Departments should critically assess the desirabil and efficacy of their comprehensive exams.*
  - *Professional Societies should gather informati about comprehensive and preliminary exams and m common practices known.*

  What is the current status? Has your Department recen reviewed the exam structure? Are there plans to chan the structure?
- Following the last meeting an informal compilation of P requirements was assembled and is available at: *www.a org/programs/education/graduate/conf2008/resourc upload/phdreqs080306.xls*. Please consider addi updating the information for your Department.
- What should be the purpose of the comprehensive exan Do they serve this purpose in your Department?

Bridge Programs to Improve Diversity

- What are the most common failure points / modes t influence retention of any graduate student? Do these cha for underrepresented students?
- What is the first step my department can take to incre retention of underrepresented students?
- What activities in my department favor majority stude i.e., are there activities that bias (either consciously unconsciously) toward the majority

Mentoring and Monitoring Student Progress

- Why should research supervisors provide mentoring to th students?
- What spheres of student education should mentor encompass? (e.g., academic development, professio development, etc.)

- In situations when the mentor and/or the mentee feel uncomfortable communicating with each other, how can the department help foster the interaction? (Should a department try to implement a specific framework to help with such situations?)
- How can faculty and other researchers be encouraged to learn about and improve mentoring practices?
- How can departments ensure that students are receiving regular and helpful feedback on their progress?

Breakout Session III Questions

Vision for Graduate Education

- What is the purpose of graduate education in physics now? Has that changed since 30 years ago? Is it going to change in 30 years?
- Who are our students and how will this change in the future?
- Given the career outcomes of our PhD graduates are we providing them the right toolset, depth, learning and thinking experiences for their careers ahead?
- What is the value of a physics education at the Bachelors level, Masters level?
- How should the above change in the future?

University, Industry and National Lab Partnership for Graduate Education

- What do universities, industry, and national labs offer to each other? What do these entities want from each other?
- Which specific attributes of a degree level cause companies to select a Bachelors, Masters, or PhD student for employment? What additional expectations are there for graduate degree holders in the workforce?
- What do industry and national labs appreciate about graduate student preparation? What would industry and national labs like to see in graduate student preparation?
- How can industry and national labs help universities form graduate students to be excellent employees and positive contributors to society?
- What types of partnerships in other fields of study have benefited universities, industry, and national labs? Can these models be applied to physics education?
- Traditionally, physics PhD graduates enter a postdoctorate period following graduation. PhD engineers frequently skip this step. What is the value of the postdoc to universities, industry, and national labs? What is the perspective about this step from new physics PhD? What attributes of the PhD engineer allow them to skip this step?

Graduate Student Concerns

- How does your department monitor students as they progress towards their degrees? What changes to your department's policies and/or degree program(s) have recently been considered or implemented as a result?
- Are incoming graduate students assisted with finding affordable housing, childcare, etc.? What career preparation services does your department offer?
- What policies are in place in your department and institution to address reports of advisor-student abuse and/or discrimination? How are faculty prepared to be effective mentors?
- What other concerns have graduate students at your institution expressed?

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