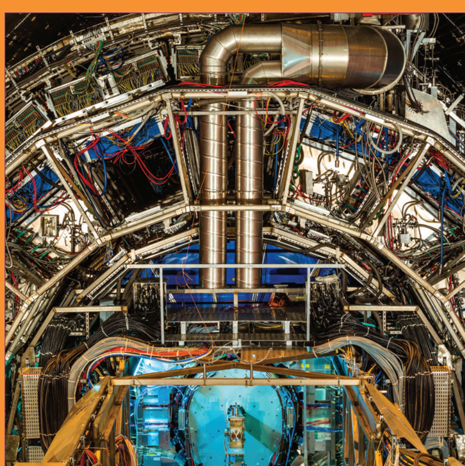


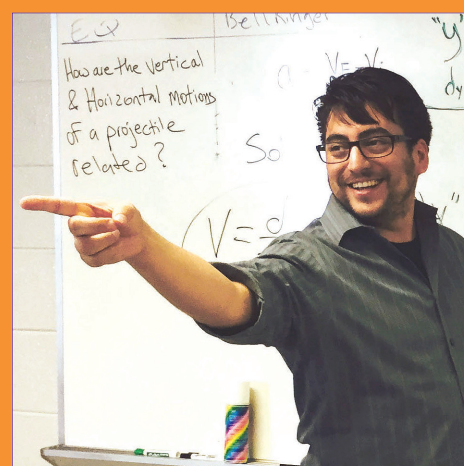

Phys21:

Preparing Physics Students for 21st-Century Careers

A report by the Joint Task Force on Undergraduate Physics Programs

Paula Heron and Laurie McNeil, Co-chairs





J-TUPP
JOINT TASK FORCE ON
UNDERGRADUATE
PHYSICS PROGRAMS

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J-TUPP is a joint task force of:

the American Physical Society

and the American Association of Physics Teachers

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Dear Colleagues,

Undergraduate physics programs have served their students well in the past for many of the careers they have entered. However, the world is changing, students are more diverse, and the needs of today's employers are rapidly evolving. In 2014 the American Physical Society (APS) and American Association of Physics Teachers (AAPT) formed the Joint Task Force on Undergraduate Physics Programs to provide guidance to physics departments seeking to improve career readiness of their graduates. The task force consisted of leaders in academic physics, physics education, industry, and national labs, and produced the report: *Phys21: Preparing Physics Students for 21st-Century Careers.*

AAPT and APS believe *Phys21* will allow physics faculty to see beyond the "standard model" of preparing majors for physics graduate school. The recommendations build on existing curricula and propose ways to enhance and improve physics programs for the diverse careers that our students take, from engineer to entrepreneur to high school physics teacher to physics researcher.

The number of undergraduate physics degrees earned each year in the United States has more than doubled since the late 1990's, opening opportunities for many more of our graduates to venture into occupations with skill sets that we, as faculty, may not fully understand. Consequently, many feel ill equipped to design a program of study that addresses the needs of these students. To continue to attract a broad and diverse set of students, we must be intentional about preparing today's students for the workforce.

We hope that physics departments will translate these recommendations into changes that will improve the strong undergraduate physics education that exists today. Engaging faculty in discussions of these recommendations will help ensure the health of the physics profession into the future.

We thank the National Science Foundation for providing funding to allow the rich conversations and fruitful meetings that shaped the ideas within *Phys21*, and we hope you will be able to use the ideas contained within the report to continue to enhance your program. If APS or AAPT can be of further assistance as you go down this road, please contact us.

Sincerely,

Homer Neal
President, American Physical Society

Janelle Bailey
President, American Association of Physics Teachers

Preface

The Task Force that produced this report comprised members representing industry, academia and the professional societies, who brought with them knowledge and insight from a variety of perspectives including entrepreneurship, physics education research and systemic change in education. We began our work by reviewing employment data, surveys of employers, and reports generated by other disciplines, many of which are quoted in this report. We also consulted with a range of outside experts, including: Crystal Bailey (APS Career Programs Manager), Cynthia Bauerle (James Madison U. and the Howard Hughes Medical Institute), Roman Czujko (AIP), Robert Doering (Texas Instruments), Miles Finn (Robins Kaplan LLP), Barbara Jones (IBM), Duncan Moore (University of Rochester), Monica Plisch (APS & PhysTEC), Kendra Redmond (SPS), John Rumble (APS FIAP Chair), and Kathryn Svinarich (Kettering U.).

In order to gain deeper insight into the experiences of recent graduates who are employed outside of academia, we commissioned a study by Rachel Scherr, of Seattle Pacific University. We also commissioned a set of case studies to better understand the experiences of departments that have developed innovative programs to support the career preparation of their students. The case studies, conducted by Stephanie Chasteen of Chasteen Educational Consulting, provide numerous concrete examples of actions, both modest and bold, that can be taken by departments of any size.

As co-Chairs, we would like to thank all of the Task Force members who contributed their time and expertise. The strength of their commitment to the futures of physics graduates was inspiring. We would also like to thank Beth Cunningham and Robert Hilborn of the AAPT and Theodore Hodapp and Renee Michelle Goertzen of the APS for their significant contributions as liaisons to the sponsoring societies. A number of external reviewers, including Steven Pollock (U. Colorado Boulder), Stefan Zollner (New Mexico State U.), Chris Hughes (James Madison U.), Mel Sabella (Chicago State U.), Ron Henderson (Middle Tennessee State U.), Brian Thoms (Georgia State U.), Melissa Eblen-Zayas (Carleton College), Alice White (Boston U.), Frances Houle (LBL), and Philip 'Bo' Hammer (AIP) provided important feedback on earlier drafts. We thank them for their constructive criticism. Finally, we gratefully acknowledge the support of the National Science Foundation through grants 1540570 and 1540574.

Paula Heron and Laurie McNeil
Co-chairs, Joint Task Force on Undergraduate Physics Programs

Table of Contents

Executive Summary

Members of academic physics departments have long prided themselves on preparing undergraduate students for careers in physics. For many faculty members, a successful physics career means an academic research and teaching position like the ones that they themselves hold. However, the overwhelming majority of people who receive a bachelor's degree in physics are employed outside academia for all or part of their careers, and are engaged in a wide variety of work. About half of this work is in the private sector, and the remainder is in non-faculty positions, high schools, the military, and national laboratories. Few physics programs are explicitly designed to prepare students for these likely career outcomes.

Physics departments that aspire to serve all of their students well will foster the knowledge and skills their students need to be successful in a wide range of careers. These careers may include, but are not limited to, graduate education in physics and related fields. To better prepare students in this way does not require a department to abandon the rigorous technical education that physicists take pride in. It does, however, require physics faculty members to become informed about the skills and knowledge valued by potential employers of their graduates, and departments to make appropriate modifications to curricular and cocurricular aspects of their programs.

This report by the Joint Task Force on Undergraduate Physics is intended to help physics programs prepare students for today's careers. It provides information about the skills and knowledge that employers of physicists are seeking, and describes ways in which physics departments can help students acquire those skills and that knowledge. Not only will departments that take up this challenge and provide the preparation their graduates need better serve all of their current students, they are also likely to attract a more diverse set of students with a broader range of career interests. In an era in which academic institutions are increasingly scrutinized regarding the return on investment that their programs provide to students (in the form of enhanced employment prospects), it is in physics departments' interest to recognize the importance of this challenge.

This report comprises an assessment of the employment landscape that physics bachelor's recipients are entering; a compilation of the knowledge, skills, and attitudes that graduates need for successful careers; a set of learning goals that physics departments can adopt to promote their graduates' success; and descriptions of ways that physics departments, perhaps with assistance from industrial partners, professional societies, and funding agencies, can ensure that those learning goals are met.

Findings

The report's findings fall into a few broad areas:

- *Employment of graduates of physics bachelor's programs*
  The overwhelming majority of physics bachelor's recipients are employed outside academia for all or part of their careers, and are engaged in a wide variety of work. Only about 5% pursue careers as physics professors.

- *Broad consensus regarding needed skills, knowledge, and attitudes*
  Studies conducted by a broad range of academic institutions, disciplinary societies, consulting groups, and economic development organizations have produced a consensus that the skills needed by college graduates to best prepare them for 21st-century careers include working well in teams, understanding how science and technology are used in real-world settings, writing and speaking well, and understanding the context in which work is now done. In line with that consensus, physics bachelor's holders working outside academia report that they regularly use and value knowledge and skills that go well beyond their knowledge of physics. Yet the development of the skills that graduates need to succeed in their jobs forms a small part of most physics programs—if it is addressed at all.

  Both graduates and their employers report that preparation for positions available to those with physics training could be significantly improved. Studies of physics graduates conclude that their technical skills should be expanded to address a wider and deeper knowledge of computational analysis tools; that they would benefit from experiences that engage them with applied and developmental work; and that the addition of professional and workplace skills such as teamwork, communication, and basic business understanding to the undergraduate physics program would make physics graduates more successful in the workplace.

- *Public expectations of college and university programs*
  Colleges and universities are increasingly expected to prepare students for high-paying jobs, and are increasingly scrutinized regarding the value and the return on investment that an undergraduate degree provides. Many students now entering college, especially those from demographic groups that have not traditionally had high college-going rates, have strong expectations that an

undergraduate degree will lead directly to employment. Especially for publicly-funded institutions, the social contract that is the basis of public funding of higher education—that in exchange for public support, colleges and universities will provide students with the knowledge and skills needed to be productive members of society—has come under question.

- *Student expectations of college and university programs*
  Many students increasingly want their studies to be associated with a societal good, such as making people's lives better or preventing damage to the environment. Such students expect their intellectual work to have relevance, authenticity, and application; and they seek out disciplines and programs such as teaching, medicine, and public health, that they perceive to have these characteristics. Programs wishing to attract these students need to make manifest the connections between the physics content at the core of the discipline and the ways in which it can be used in broader contexts.
- *Relationship between career preparation and graduate school success*
  Reframing a physics program to better prepare students for a broad range of careers can also enhance the success of students who choose to pursue graduate education in physics. Since only about one-third of physics Ph.D. recipients end up in academic careers, even students who plan to obtain graduate degrees will benefit from developing skills and knowledge that are valued outside the academic community. Further, many of the same skills and much of the same knowledge are also keys to success in graduate school and as a faculty member.
- *Elements of successful programmatic change*
  (1) Get to know your students and the job opportunities available to them. (2) Adopt learning goals that specify the knowledge and skills your students will develop. (3) Map the learning goals to existing program components and identify gaps. (4) Develop a plan to fill those gaps and implement it. (5) Assess the results and use the assessment to inform further program modifications.

Goals that promote career readiness, and ways to achieve them

The Task Force has identified a set of learning goals that encompass physics-specific knowledge, scientific and technical skills, communication skills, and professional and workplace skills. A program that offers its students the opportunity to acquire this knowledge and these skills will better meet the needs of its graduates.

- *Physics-specific knowledge*
  Learning goals for physics-specific knowledge include the ability to use fundamental concepts such as conservation laws to solve problems, and competency in applying basic laws of physics in diverse topic areas and applied contexts. They also include the abilities to represent physics concepts in multiple ways and solve problems involving multiple topic areas and disciplines.
- *Scientific and technical skills*
  Learning goals for scientific and technical skills include the abilities to solve ill-posed problems through experiments, simulations, and analytical models; determine follow-on investigations; and identify resource needs. They also include competencies in instrumentation, software, coding, and data analytics.
- *Communication skills*
  Learning goals for communication skills include the ability to communicate orally and in writing with audiences that have a wide range of backgrounds and needs.
- *Professional and workplace skills*
  Learning goals for professional and workplace skills include the abilities to work in diverse teams; obtain knowledge about relevant technology resources; demonstrate familiarity with workplace concepts such as project management, budgeting, quality assessment, and regulatory issues; demonstrate effective management of difficult situations (including classrooms); and demonstrate awareness of career opportunities for physics degree holders and effective practices for job seeking.

The Task Force has also identified ways in which physics programs can be modified to achieve the above learning goals through collaborative efforts with other disciplines and employers, modification of degree requirements, updated course design, and incorporation of co-curricular activities. The strategies adopted or developed will depend significantly on local conditions, including the resources available, the aspirations of the student body, industries in the region, etc. There is no one-size-fits-all approach.

- *Partner with other units and with employers to develop new opportunities*
  Physics departments can engage in collaborative efforts with other units on campus and with employers of physics graduates, particularly department alumni/ae, to provide students with immersive experiences in the workplace through co-op stages or internships, or through intensive interdisciplinary programs on themes such as innovation and entrepreneurship.

- *Redesign the major*
  Learning goals can be pursued through changes to degree requirements, whether through increased flexibility that allows students (in partnership with advisors) to plan programs appropriate for their chosen career paths, or through formal tracks that incorporate carefully-chosen electives. Broad learning goals such as those associated with professional or communication skills can be infused into the curriculum at multiple points, and can also be addressed coherently in a single integrative experience such as a capstone course.
- *Design or redesign courses*
  Many existing courses can be adapted to feature applications from industry, medicine, engineering, teaching, etc., and to introduce students to industry-standard tools and software packages. Courses can also be adapted to incorporate practice with communication and professional skills through team projects, oral presentations, for example. Courses and seminars that focus on career preparation can expose students to employment options and ensure they are well prepared to conduct job searches and enter the workforce.
- *Leverage co-curricular activities*
  Co-curricular activities may allow departments relatively simple ways to offer career readiness opportunities for students. For example, hosting visits by physicists in non-traditional careers (especially alumni/ae), engaging students in departmental outreach programs, and involving students in teaching activities can also raise awareness of career paths and help students develop professional skills.

Recommendations

The report makes a series of recommendations, primarily addressed to academic physics departments. Although physics departments are where students are prepared for physics careers, professional societies and funding agencies also have roles to play, as noted above. Some of the report's recommendations are therefore addressed to those institutions.

Physics departments and faculty members wishing to effectively prepare graduates for success in diverse careers should take the following actions:

- Modify their programs to ensure that students have opportunities to acquire the knowledge and skills needed for the careers that will be available to them.
- Promote a departmental and faculty culture that values non-academic careers and the students who pursue them.
- Provide mentoring and career advising to all students throughout the undergraduate program.
- Identify the types of jobs that program graduates are currently finding, are likely to seek in the near future, or could seek if provided with appropriate preparation.
- Use the findings of this report as a guide to understanding the knowledge and skills needed to do those jobs.
- Adopt learning goals relevant to the knowledge and skills that graduates will need.
- Use the findings of this report to guide strategic planning for program improvement and enhanced student recruitment through faculty development, course modifications, changes in program requirements, and co-curricular activities that include fostering contact between students and physicists outside academia.
- Assess whether the changes made achieve the learning goals (perhaps with the assistance of external review), and use the results of the assessment to further modify and improve the program, maintaining a cycle of continuous program improvement based on experimentation and assessment.

Professional societies can assist physics departments and physicists outside academia that wish to enhance the preparation of physics graduates for diverse careers. We therefore recommend that American Physical Society (APS), American Association of Physics Teachers (AAPT), and other physics professional societies take the following actions:

- Provide recognition for faculty members, physics departments, and physicists outside academia for outstanding contributions to the preparation of students for diverse careers.
- Offer career readiness professional development activities for students and workshops to assist current faculty and career services personnel in providing career preparation activities.
- Provide forums for the interchange of ideas on physics and physics careers that are "applied" and "industrial."
- Ask physics student organizations (Society of Physics Students, APS Women in Physics groups, etc.) to advocate for the adoption of the recommendations of this report and develop student-based programs that implement them.
- Promote education in career readiness through society activities, and engage society members outside academia in these efforts.

While individual institutions are responsible for providing high-quality physics programs, external funding can catalyze programmatic change. We therefore recommend that federal agencies and private foundations that support physics research and education take the following actions:

- Fund applied research projects in academic settings that offer students opportunities to acquire skills and knowledge needed for success in diverse careers.
- Fund curricular and co-curricular development and research projects that prepare students for diverse careers.

About the Joint Task Force on Undergraduate Physics Programs

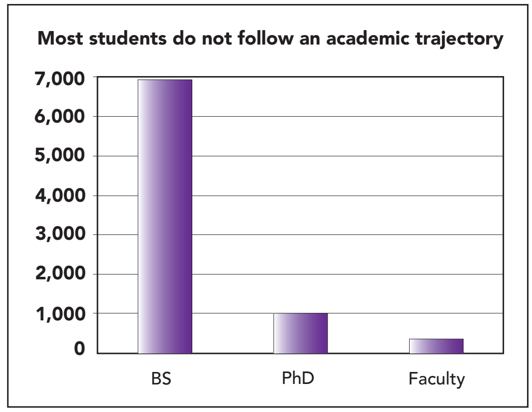
The Joint Task Force on Undergraduate Physics Programs (J-TUPP) was convened by the American Physical Society and the American Association of Physics Teachers and charged to answer the following question: ***What skills and knowledge should the next generation of undergraduate physics degree holders possess to be well prepared for a diverse set of careers?*** J-TUPP was asked to provide guidance for physicists considering revising their department's undergraduate curriculum to better prepare students for diverse careers, and to include relevant recommendations on content, pedagogy, professional skills, and student engagement. J-TUPP's findings are contained in this report, followed by recommendations for action by physics departments, professional societies, and funding agencies.

1 A Call for Action

Academic physics departments have long prided themselves on preparing "the best and the brightest" students for careers in physics. The successful careers of faculty members offer evidence that undergraduate physics programs provide good preparation for academic research and teaching positions.

It is natural that many faculty members imagine that a successful career in physics will follow the path they themselves took, from undergraduate degree to graduate study to a faculty position, with perhaps one or more postdoctoral positions along the way. However, this path has never been the one followed by the majority of people who receive an undergraduate degree in physics. (See Figure 1.) According to the American Institute of Physics' (AIP) Statistical Research Center, fewer than 5% of U.S. physics bachelor's graduates end up employed as physics professors (though some may pursue academic careers in other fields, such as engineering). The overwhelming majority of people who receive a bachelor's degree in physics are employed outside academia for all or part of their careers, and are engaged in a wide variety of work, about half of which is in the private sector. Few physics programs are explicitly designed to prepare students for this likely career outcome.

Figure 1

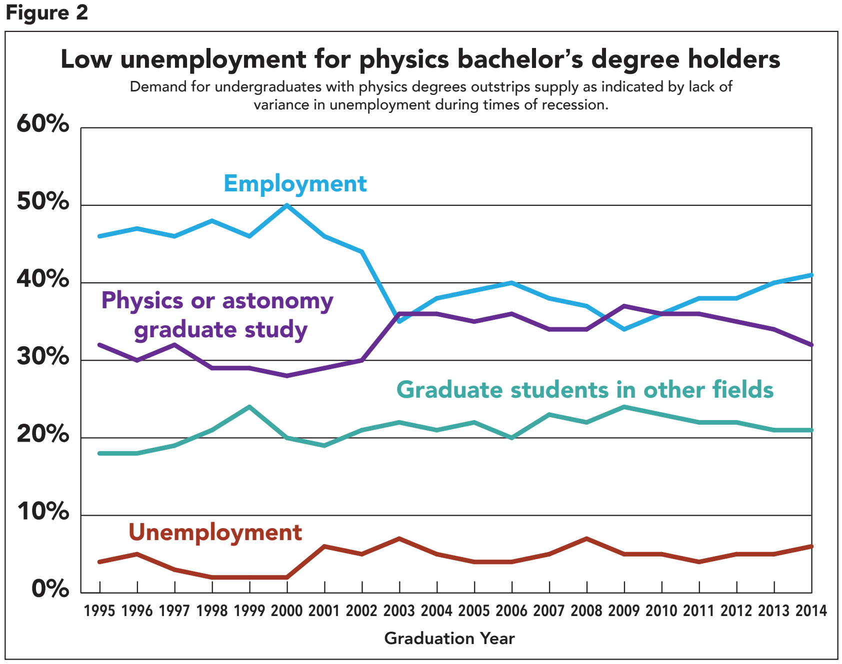


National Center for Educational Statistics Integrated Postsecondary Education Data System: IPEDS Completion Survey

The good news is that nearly all physics majors who seek employment after completing their bachelor's degrees find a job of some sort: Only 4% of majors graduating in 2011 and 2012 were unemployed one year after graduation [1], and only 6.2% of physics graduates ages 22 to 27 were unemployed in 2014, though this figure is higher than those for graduates in other science, technology, engineering, and mathematics (STEM) fields such as chemistry (4.7%), biology (5.1%), mathematics (5.9%), or computer science (3.6%) [2]. While the average unemployment rate in the overall economy was around 10% during the 2007–2008 period, it was only 6.8% for those holding physics degrees. General trends can be seen in Figure 2, which shows the percentage of recent graduates in graduate school, in the workforce and unemployed. Recent reports from the AIP Statistical Research Center and the APS Committee on Careers and Professional Development [3] indicate that in 2006, average starting salaries in the private sector were $45,000 for B.S. physics degree holders, $60,000 for M.S. physics degree holders, and $80,000 for Ph.D. physics degree holders. More recent, 2014, data [2,4] show that the average starting salary for a physics bachelor's graduate was in the $50,000–$65,000 range. (see Figure 3 on the following page.) As noted in the APS report referenced above, "An investment in a physics education can be one of the rare instances where the financial return is fast—about four years for a bachelor's degree—and will continue to pay off at an increasing rate throughout your professional career" [3].

However, these generally positive data hide other important trends. A sizable fraction of physics bachelor's recipients—30% according to AIP's most recent report [5]—were actually underemployed, meaning they were in positions that do not typically require physics training. And many who are using their physics training are so-called "hidden physicists," whose job titles and descriptions do not explic-

Figure 2



AIP Statistical Research Center

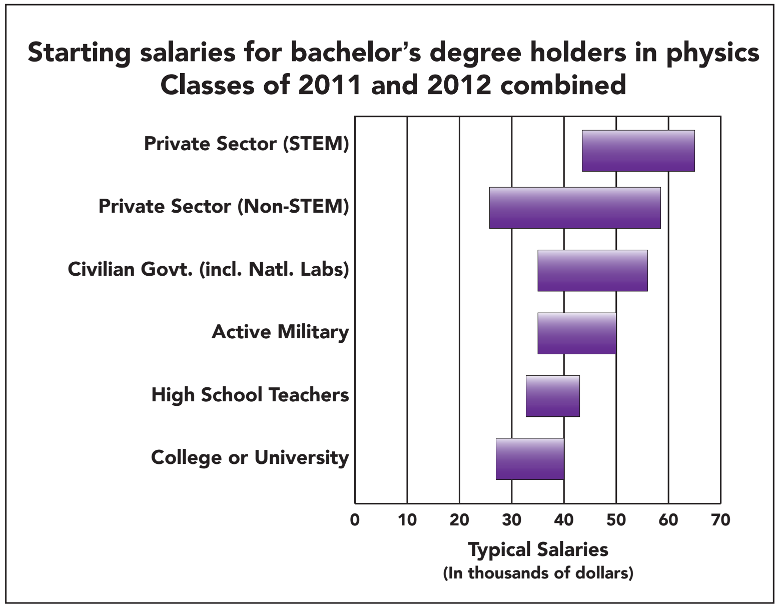
Figure 2: Data in the figure excludes respondents who were pursuing employment or graduate study outside the US. In recent years about 4% of the respondents indicated they left the U.S.

itly mention "physics." (This is the case for many engineers, for example.)

Both graduates and their employers report that physics graduates could be better prepared for positions available to those with physics training. This is equally true for recipients of Ph.D. degrees in physics, almost half of whom occupy positions outside academia one year after receiving their degrees [6], and more of whom move to private-sector or government positions after completing a postdoc.

The knowledge and skills that physics graduates working in the private sector report they regularly use and value go beyond their knowledge of physics. Tasks such as working in teams, technical writing, using computer programming to solve problems, applying physics to solve interdisciplinary problems, designing and developing products, managing complex projects, and working with clients are central to graduates' everyday work. Yet the development of the skills necessary to succeed at these tasks forms a small part of most physics programs, if it is addressed at all. In some degree programs, such skills and experiences are offered through research experiences and advanced course work as well as through group work in reformed physics instruction. However, if these skills were more explicitly emphasized in undergraduate physics programs, we could better prepare physics graduates for all career paths.

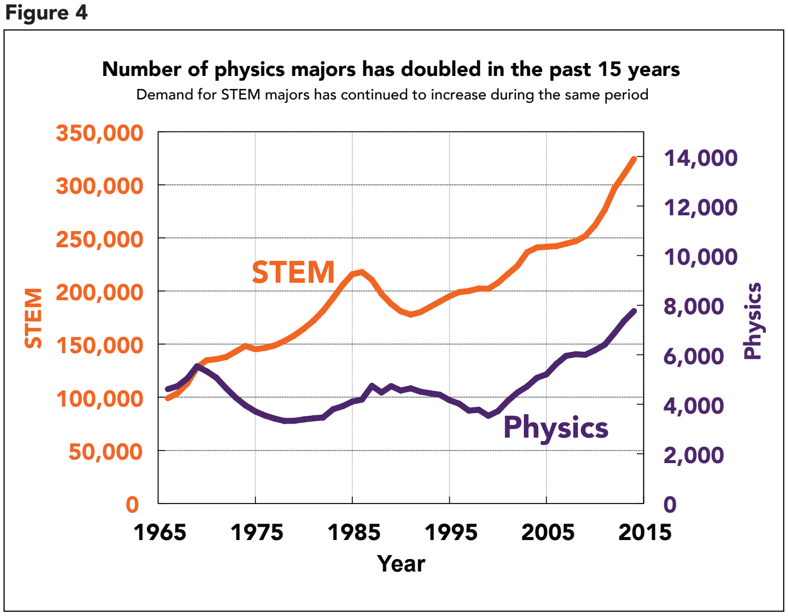
Figure 3*



AIP Statistical Research Center

Over the past 15 years, not just the job market but the physics education landscape has changed dramatically. The number of students pursuing undergraduate physics majors has more than doubled as shown in Figure 3 [7]. At the same time, physics, like many other STEM disciplines, has become increasingly interdisciplinary, requiring that students become proficient in areas beyond the traditionally-defined boundaries. And although students are still drawn to physics just as we were, we can no longer count on droves of the "best and brightest" knocking down our doors to tackle the most difficult—and most interesting—problems. Physics has real competition from the other science disciplines, engineering, information technologies, and cross-disciplinary programs, all of which offer students exciting challenges. Our students will go on to occupations that may have been unthinkable for us, or that may not even exist today. Finding ways to help them succeed, and to help them understand the opportunities that a physics education provides as they venture forward, should be a key focus of our educational efforts. Doing so also provides an opportunity to enhance the participation of traditionally underrepresented groups such as women and ethnic minorities.

Figure 4



National Center for Educational Statistics Integrated Postsecondary Education Data System: IPEDS Completion Survey

In addition, the need for qualified physics teachers is greater now than at any previous time in U.S. history [8]. School districts report that physics is the highest-need area among all academic disciplines [9].

* Figure 3: Figure includes only bachelor's degree recipients in full-time, newly accepted positions. Typical salaries are the middle 50%, i.e., between the 25th and 75th percentiles. STEM refers to positions in natural science, technology, engineering, and math. Data are based on respondents holding potentially permanent jobs in private-sector STEM positions (498), private-sector non-STEM positions (114), civilian government positions (52), the active military (44), high school teaching positions (82), and universities or colleges (84).

The Animator - Ernest Petti
Technical Supervisor, Walt Disney Animation Studios

Reproduced with permission from *Radiations.* © 2015, AIP.

Like many physicists, Ernest Petti has always enjoyed learning and discovering how and why things work. He majored in physics and computer science at John Carroll University in University Heights, Ohio. After graduation, he developed prototype software for cockpit displays at the airplane manufacturer Rockwell Collins. But Petti soon realized he really wanted to use his physics and computer science training to entertain people. So he earned an M.S. in computer science at the University of Iowa in Iowa City, focusing on computer graphics.

Petti then landed a job at Walt Disney Animation Studios in Burbank, California. He started in Disney's software group developing lighting and fur-generation software. He then became a lighting artist on Chicken Little and other productions, where he wrote code to control how light and shade physically behave in scenes, to achieve the director's artistic goals.

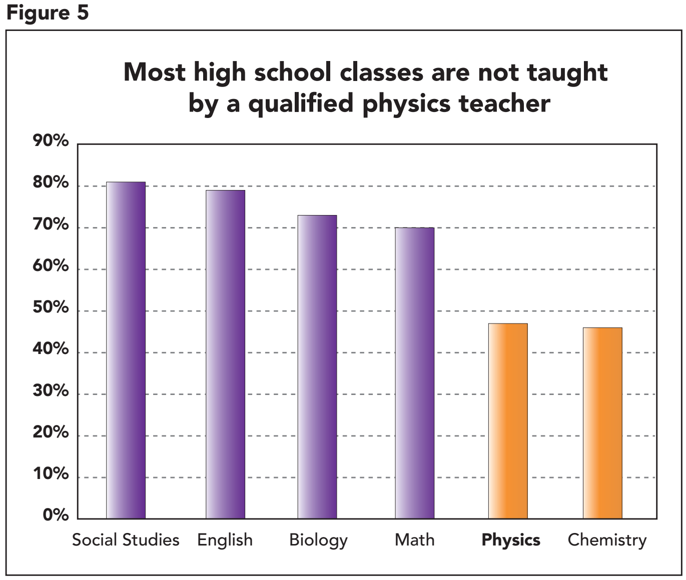
Recently, Petti was the technical supervisor on Zootopia, an animated film released in 2016. In this role he coordinated all the research and development for the film, worked with Disney's technology groups on tool and process enhancement, supervised the technical directors on the show, and did show-specific research and development.

In all his roles, Petti tries to provide artists with a physically plausible but artistically controllable tool set. "I am constantly referring back to my background in physics," he says.

Only 47% of physics classes are taught by a teacher with a degree in the subject, compared with 73% of biology classes and about 80% of humanities classes as shown in Figure 5. [10]. Physics students who become physics teachers are in exceptionally high demand, and report high levels of job satisfaction [5]. Physics faculty must recognize that they have a responsibility to prepare the physics teachers who will teach their future students.

It is worth restating that 95% of undergraduate physics students will not become professors. As a profession we cannot afford to ignore the needs of 95% of our undergraduate students, if we expect an education in physics to remain relevant in the 21st century. While there will always be a cohort of students who are drawn to physics purely because of its intellectual attractions and its roots in basic research, physics departments cannot in good conscience neglect their responsibility to provide the best possible preparation for all students. Departments that take up this challenge will not only better serve all of their current students, but are also likely to attract a more diverse set of students, with a broader range of career interests.

Figure 5



National Center for Educational Statistics, School Staffing Survey 2007-2008

To meet this important and growing need, the American Physical Society (APS) and the American Association of Physics Teachers (AAPT) convened the Joint Task Force on Undergraduate Physics Programs (J-TUPP) and charged it to answer the following question: *What skills and knowledge should the next generation of undergraduate physics degree holders possess to be well prepared for a diverse set of careers?* Our report provides guidance for physicists considering revisions to their undergraduate curricula to improve the education of a diverse student population, and for professional societies and funding agencies that provide crucial support for these efforts. It also includes recommendations on content, pedagogy, professional skills, and student engagement.

Figure 5: Only 47% of physics classes are taught by a teacher with a degree in the subject, compared with 73% of biology classes and more than 80% of humanities classes.

2 The Need for Change

A. Background

Academic institutions are by their nature conservative [11], in that they tend to believe in the value of established and traditional practices. Many members of such institutions might say that change should be undertaken only when improvement is both demonstrably needed and likely to be produced by a proposed change. In other words, "If it ain't broke, don't fix it."

In the private sector, by contrast, satisfaction with the status quo is a recipe for extinction, and the need to continuously innovate and improve has long been understood. Innovation-supporting environments also attract employees and foster dynamic, resourceful, and successful organizations.

The academic physics community has recognized the need for change in the past, as when the number of bachelor's degrees awarded in physics in the United States declined steadily in the early 1990s. This crisis prompted APS, AAPT, and AIP to generate the Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) report in 2003 [12], and to undertake the Doubling Initiative in 2007 [13]. These efforts have been among the factors that led to the doubling of the number of physics bachelor's degree recipients between 1999 and 2013 [7].

Although the physics community as a whole does not currently find itself in the state of crisis today that it did in the 1990s, less-obvious challenges are putting pressure on our undergraduate programs. There remains a concern that a number of smaller academic physics programs still face threats of closure due to low numbers [14] (and many of the programs under threat disproportionately serve under-represented groups). There are pressures on healthy enrollment in physics programs that include international competition, changing demographics and preparation among the college-age population, changing student interests, competition from engineering or applied science and information technology programs, rapidly evolving employment opportunities, and structural changes in the economy.

Many students now entering college, especially those from demographic groups that have not traditionally had high college-going rates, have strong expectations that an undergraduate degree will lead directly to employment. Many members of the public expect colleges and universities to prepare students for high-paying jobs, and such institutions are increasingly scrutinized regarding the value and the return on investment provided by an undergraduate degree. Especially for publicly funded institutions, the social contract that is the basis of public funding of higher education—that in exchange for public support, colleges and universities will provide students with the knowledge and skills needed to be productive members of society—has come under question, and government support is declining in many states.

Many students who enter college intending to major in physics shift to other majors before graduating, and relatively few transfer into physics majors from other declared majors, which reduces the number of physics degrees awarded. As pressures for departments to demonstrate performance using metrics such as graduation rates are more likely to increase than decrease in coming years, it is more prudent to take action to seize opportunities as they arise rather than engage in post-crisis emergency response. We have an opportunity to act now, before the next crisis in undergraduate (and graduate) enrollment hits.

Although the focus in most physics departments is on preparing graduates for academic careers, the discipline of physics nevertheless has a remarkable record of effectively preparing degree holders for secure employment in domains that range far outside of their formal area of education. The salary data in Chapter 1 demonstrate the value of physics degrees. A department that prepares its graduates for private-sector employment therefore provides them with the opportunity to pursue satisfying and remunerative careers.

The return on investment provided by a physics degree, and the associated competencies mastered in obtaining it, belie one other aspect that is easy to miss. Only a fraction of degree holders actually worked in a job with a title that involved physics—most were so-called "hidden physicists." As pointed out by Jeffrey Hunt of the Boeing Corporation [15], physicists can be nearly as successful in a broad range of disciplines as can those with engineering degrees. In fact, engineers educated in a particular discipline find that their expertise rapidly diminishes outside of their area. Graduate physics degrees are not exempt from this pattern. Although there is a myth that Ph.D.-earning physicists typically become faculty members, only about 35% of people with Ph.D.s in physics end up working in four-year higher education institutions [16].

The bachelor's degree recipients who do not go on to graduate study in physics are likely to spend the majority of their careers outside of academia. In 2012, among B.S. holders of physics degrees who were in the workforce, initial employment was 61% in the private sector, 13% in colleges or universities, 8% in high schools, 6% in the military, and about 5% in national laboratories [5]. (See Figures 7 and 8.)

The past success of physics graduates is a testament to the value of the discipline and the efforts of those who pursue it. However, the fact that recent physics bachelor's graduates are pursuing diverse careers cannot be used as evidence that the preparation they received in their undergraduate programs provided the range of skills and knowledge that they most needed in those careers. Much of the success of undergraduate physics degree holders may be due to inherent factors associated with success in obtaining a degree in physics, including intellectual ability and flexibility, persistence, and a high tolerance for accepting and overcoming initial failure.

Despite the emergence of new disciplinary sub-areas such as computational physics, biophysics, and materials physics, the undergraduate physics curriculum has changed little over the last 50 years. In addition, few physics departments have adopted the goal of effectively preparing high school physics teachers, resulting in dramatic shortages and inadequately-prepared pre-service teachers [8].

As described in more detail later in this report, surveys indicate that skills valued in the workplace include the ability to effectively collaborate, solve technical problems, program high-level simulations, and engage in computational thinking. That the discipline of physics provides an incubator in which these very skills are developed explains why the physics degree at all levels is so highly valued in the workplace.

If undergraduate physics programs are to enhance their graduates' prospects for employment in diverse careers that are not normally described as "physics jobs," it is critical that they explicitly include opportunities to acquire the skills and knowledge needed in these jobs. As this report indicates, these opportunities can be created within the physics program, and can broaden the physics graduate's employability without diminishing his or her traditional physics capabilities. If students have these skills and knowledge, they are more likely to be hired, will be more confident in their jobs, will require less training, and will be more productive more quickly. They are also more likely to be successful in graduate study in physics or other fields. A program that offers these benefits to its graduates is likely to attract more majors, including from groups traditionally underrepresented in physics, since in many cases these individuals are likely to require more explicit pathways from degree to career. Providing such benefits to its students will help a department to thrive.

B. Incentives for change

We must ask, *are our undergraduate physics programs preparing 21st-century graduates as effectively as they could (or should), and are these programs missing out on the talents of students who choose not to enter physics because the programs lack explicit career-readiness preparation?*

The incentives for undertaking programmatic change to better prepare physics students for all the careers they may pursue are many, but they can be grouped into three broad themes: improving the program's ability to attract, retain, and prepare students; attracting new resources; and maximizing program impact. Different institutions may find different mixes of these themes to be more salient, but all will benefit from responding to these incentives.

1. Students

Within the scientific community there is a broad consensus regarding the need to update the curriculum taught in colleges and universities, so that students will gain the knowledge, skills, and attitudes needed to succeed in 21st-century scientific careers. Reports from various disciplines on this topic include:

- *Transforming the Preparation of Physics Teachers: A Call to Action*, Task Force on Teacher Education in Physics (T-TEP), 2012 [8]
- *Strategic Programs for Innovations in Undergraduate Physics: Project Report*, AAPT, 2003 [12]
- *Undergraduate Chemistry Education: A Workshop Summary*, National Academies Press (NAP), 2014 [17]
- *Future of Undergraduate Geoscience Education: Summary Report*, Jackson School of Geosciences, the University of Texas at Austin, 2014 [18]
- *Adapting to a Changing World: Challenges and Opportunities in Undergraduate Physics*, NAP, 2013 [19]
- *Transforming Undergraduate Engineering Education: Phase I: Synthesizing and Integrating Industry Perspectives*, American Society for Engineering Education, 2013 [20]
- *Vision and Change in Undergraduate Biology Education*, American Association for the Advancement of Science (AAAS), 2011 [21]
- *National Issues in Industrial Physics: Challenges and Opportunities*, APS, 2015 [22]
- *Developing a National STEM Workforce Strategy: A Workshop Summary*, NAP, 2016 [23]
- *Revisiting the STEM Workforce*, National Science Foundation (NSF), 2015 [24]
- *2015 CUPM Curriculum Guide to Majors in the Mathematical Sciences*, Mathematical Association of America, 2015 [25]

AAAS's 2011 "*Vision and Change*" report nicely summarizes the larger context of the need for change, stating: "The following questions should be asked: What knowledge and skills are relevant to the subject area? What should students know and be able to do at the end of the unit or course? What do proficiency and mastery in the subject area at this level in the curriculum (e.g., an introductory course or capstone seminar) look like? What evidence would I accept that a student has achieved proficiency or mastery across the relevant content and skills identified? What evidence would convince my colleagues?" [21] Physicists have an opportunity to take the lead in responding to these questions, and thereby maintain the broader relevance of our discipline.

To supplement the findings presented in these studies, J-TUPP undertook a *Study of Physics Majors in the Workforce* (the full study report is included as Appendix 2 to this document) and conducted numerous interviews with physicists from a variety of occupations. In the J-TUPP study, physics bachelor's degree recipients working in the private sector reported a desire for more programming skill development, more experience in industrial and applied physics environments, and a better understanding of the marketability of their degrees. In all cases, there was a clear message that the current physics curriculum is not developing key skills, including contextual understanding of core science concepts; real-world and multidisciplinary applications of core science concepts; skills for solving complex and ill-defined problems; collaboration and communication skills; software, technology, and research skills; lifelong learning and innovation skills; and facility with business concepts.

<5% Percentage of physics bachelor's graduates who will become physics or astronomy professors

Reforms to K-12 education are also setting up new opportunities for reforming the undergraduate physics curriculum. If these reforms become widely successful, many among the next generation of students will come to college having experienced inquiry-based science programs and science and engineering courses based on the Next Generation Science Standards (NGSS) [26]. Those students will have had learning experiences that involve defining problems, planning and carrying out investigations, analyzing and interpreting data, developing and using models, developing explanations and designs based on evidence, applying and using scientific knowledge, and communicating information. Students who have had NGSS-based instruction will be familiar with what standards writers identified as the three dimensions of science education: science and engineering practices, crosscutting concepts, and disciplinary core ideas. K-12 students are expected to be able to engage in the core practices and apply crosscutting concepts to make connections across disciplines and to analyze new problems.

Undergraduate physics programs can help students build on this type of learning. However, since the pedagogical approaches promoted in the NGSS are not broadly used across many undergraduate physics programs today, with the possible exception of research opportunities, physics faculty will need to make programmatic enhancements to take advantage of the changes in student preparation. The need for such changes across undergraduate science programs is supported by research on learning [27]. Such changes will therefore provide more opportunities to help students develop the skills valued by employers while improving physics learning. However, these opportunities must be explicitly designed into the program, and their role must be made clear to students as well as faculty.

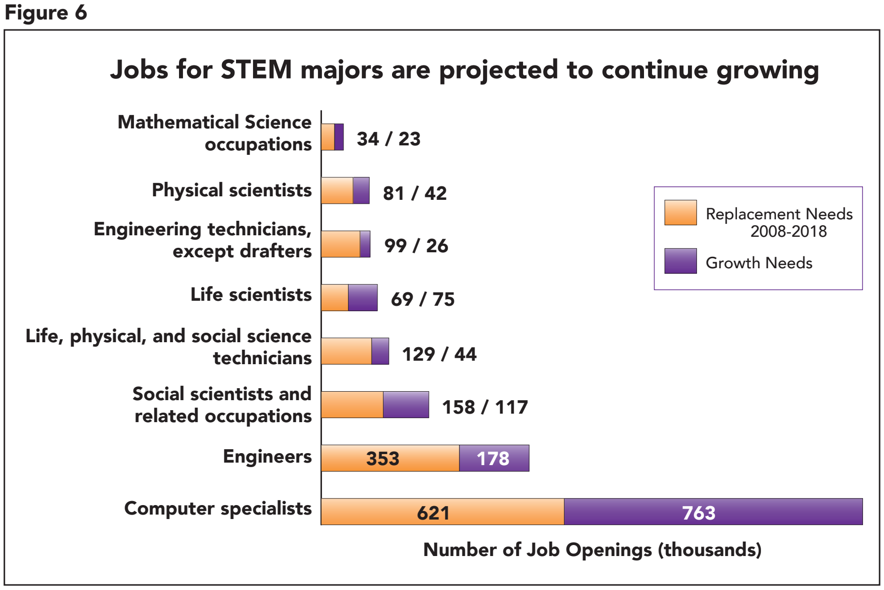
Enhancing the extent to which a physics degree prepares its graduates for future employment will bolster the health and vitality of our undergraduate programs. Although the decline in physics enrollment in the 1990s has been reversed, and the number of physics bachelor's degrees awarded each year has increased for the past 14 years [28], physics degrees still constitute only 5.4% of bachelor's degrees awarded in the physical sciences and engineering, and only 0.3% of degrees awarded in all fields [29]. This is not just a problem of low recruitment, but also of poor retention: Only one-fourth of the students who enter college considering majoring in physics end up graduating with that major. The rest switch majors for a variety of reasons, many of them unrelated to students' ability to complete the physics program [30]. Further, women and racial and ethnic minorities are underrepresented among physics graduates compared to their representation in the college population [31-34].

Many physics departments, especially those in smaller institutions, are under pressure because of low current or likely future enrollments [14]. While some students with a passion for physics will presumably always be drawn to and complete degrees in our discipline, there are almost certainly additional potential physics students who are choosing other majors because they and/or their parents are not aware of what career options exist for someone with a physics degree, outside of academic research. If physics departments could make clear to students—and their parents and high school guidance counselors—that majoring in physics provides flexible preparation for a wide variety of rewarding careers, more students would likely choose to major in physics. This is especially important for attracting students from a more diverse range of backgrounds and interests, including first-generation college students and those from groups traditionally underrepresented in physics, who will constitute the majority of the college-age population in the future [35,36]. The economic circumstances of many of these students require that they focus on their future employment prospects as well as on their passion for a subject. By enhancing those prospects (and the awareness of them), physics departments can attract many students who might otherwise choose fields such as engineering that have more obvious career trajectories.

Another draw for students, particularly women, is the recognition that the major provides a path to careers that address societal problems [37]. The computer science department at Stanford, in part by stressing this feature of that discipline, has made computer science the university's most popular major for women [38]. Many physics careers address societal issues, often through the development of new technology in areas such as renewable energy, communications, and biomedical devices.

Indeed, physics plays an essential role in innovation. Nearly all technologies implemented in modern products and processes emerged from physics-intensive laboratories. Yet innovation *per se*, while prized in other areas such as engineering and business, is not stressed as a key component in physics education. Physics could be a more attractive discipline to a broader range of prospective students if faculty helped students connect their studies to opportunities for innovation that generate solutions to important real-world problems. Students need explicitly-designed opportunities to understand the relationships between physics research topics and real-world applications. These opportunities can also broaden the views of students headed to academic careers, in which they can pursue interesting research projects related to current societal problems. Such projects can also open up a broad range of sources of research funding.

Figure 6



President's Council of Advisors on Science and Technology: "Engage to Excel," 2012

Another physics career with a direct impact on society is high school teaching. In addition to their responsibility to prepare students for a broad range of scientific careers, physics departments have an enlightened self-interest in preparing well-qualified high school physics teachers. High school students who have been introduced to physics by a teacher with a substantial physics background as well as significant pedagogical content knowledge specific to physics are more likely to develop and maintain an interest in physics and be well prepared to pursue a physics degree. Nationally there is a significant shortage of well-prepared physics teachers, with only about 46% of all high school classes having a teacher with significant knowledge of the subject [8]. By providing opportunities for physics students to develop the skills and knowledge needed for effective high school teaching, physics departments can influence the education not only of their future majors but also of many young people who will not become physics majors and may not even attend their institution, but who become responsible citizens. They can also help raise the profile of teaching as a valued profession.

Reframing a physics program to better prepare students for a broad range of careers can also enhance the success of students who

Figure 6: Physics majors can often find employment in many of these areas.

choose to pursue graduate education in physics. As noted earlier in the chapter, only about one-third of physics Ph.D. recipients end up in academic careers. So even students who plan to obtain graduate degrees will benefit from developing skills and knowledge that are valued outside academia. Further, many of the same skills and knowledge play an important role for success in graduate school and as a faculty member. Virtually all graduate students are likely to work in teams, engage in technical writing, use programming to solve problems, assess the quality of their findings, design and develop apparatus and computational tools for their research, and participate in the management of complex projects. Those Ph.D. recipients who become faculty members will be well served by this preparation as they are called upon to manage research teams and staff, to oversee research and educational programs and budgets and handle legal and regulatory issues, and to innovate to develop new programs, much like their counterparts in the private or government sectors.

2. Resources

Beyond opportunities to increase the number, diversity, and quality of the students they attract, physics programs can reap additional benefits from preparing their graduates more effectively for a broad range of careers. Connecting the research done in the academic setting with topics of interest to the private sector and government will not only help students who participate in that research gain the knowledge and skills needed in their careers, but can also help faculty members establish new collaborations and contacts outside academia, which can lead to new sources of research funding or to equipment donations. Making these connections locally will further enhance a department and its students' undergraduate experiences, and add to the employability of its students. The broad applicability of even seemingly esoteric physics topics (see for example projects undertaken by Google X [39] or Microsoft Station Q [40]) means that many physics faculty members can find ways to connect their research to industry, to both their benefit and that of their students.

As physics faculty members are doubtless well aware, careers in the private sector are often more lucrative than those in academia. A physics graduate who is successful in industry is likely to be able to give back to the institution that helped make that success possible. A physics program that explicitly and visibly prepares its graduates for success in high-paying jobs will be in a better position to persuade those graduates to donate funds to help future students succeed in the same way, and is likely to have more graduates who have the capacity to become generous donors. In this way, serving students also serves a department's interests. Corporate support for research and other aspects of university physics programs (such as scholarships or symposia) is also generally directed to departments that produce graduates that the corporation has hired or wishes to hire in the future. A department that does a good job of preparing graduates for such positions can therefore receive other benefits. And again, since many bachelor's recipients find employment in the local area, enhancing these kinds of connections with local companies can be a key to success.

3. Impact and reputation

Reframing a physics program to better prepare students for a wide range of careers can not only improve student recruiting and increase available resources, but can also increase the broader impact a department is able to have beyond its boundaries, and enhance its reputation within and beyond the university. It can enhance the connections between the physics department and other related disciplines within the university with similar goals for their students, encouraging joint research projects and possible double majors for students. Finally, the changes in physics programs recommended in this report will allow departments to enhance their reputations within the physics community and recruit excellent faculty with a wide range of research interests. A growing student enrollment allows the number of faculty members in the department to increase, and a department that takes a wide view of the range of interesting physics problems and has a strong and engaged student population will be attractive to a broader segment of researchers.

30% **Percentage of physics bachelor's graduates who enroll in graduate school in physics**

Reframing a physics program to provide better preparation for a wide range of careers can lead to an increase in the number of students recruited into and retained in the physics program—important goals for both the department and for the university. As described elsewhere in this report, such actions can also lead to more collaborative efforts with other academic units in the university and with local businesses and industries. Such efforts can enhance the reputation of the department within the university and in the local community, and thus potentially provide additional resources for the department and its programs.

The remainder of this report outlines the steps a department can take to ensure its graduates are well prepared for a range of career paths that build on the core physics curriculum. Chapter 3 summarizes several national surveys and studies that reveal what knowledge, skills, and abilities students and their employers desire, and what gaps exist between those and the standard undergraduate physics program. This chapter also reviews how other disciplines have acknowledged the changing employment landscape for their graduates, and how some universities have responded by crafting outcomes statements aimed at providing broad and flexible career preparation for their graduates. These discussions set the stage for Chapter 4, which contains a set of proposed learning goals intended to inform departments' efforts to examine and, if necessary, modify their programs. Chapter 5 then provides advice on strategies for implementing program elements intended to support the learning goals. Chapter 6 discusses how departments and administrative leadership at institutions can manage the change process in a long-term and sustainable manner. Finally, we provide recommendations for how professional societies and funding agencies can promote these diverse career efforts.

The Engineer
Amethyst Radcliffe, Materials Engineer, PPG Aerospace

Adapted from the July 2016 issue of *APS News*, © APS.

As a California State University, Long Beach undergraduate, Amethyst Radcliffe gravitated toward the borderlands of physics and chemistry—how the arrangements of atoms and electrons give solid materials their bulk properties. She studied enzymes in a biochemistry lab, took courses to learn lab techniques such as X-ray diffraction, vacuum sputtering, and atomic force microscopy, and did several summer research internships.

As Radcliffe neared graduation, she realized she wanted to work in a fast-paced environment and tackle problems that would have immediate real-world impacts or could lead to new products. So she took a job as a materials engineer at the paint and coatings manufacturer PPG Aerospace in Sylmar, California.

Radcliffe develops thin metal films that keep the windows, windshields, and canopies of airplanes ice free, and that shield planes from electromagnetic interference. Much of what she does is condensed matter physics—conducting theoretical studies to predict the properties of a particular material, and experiments to test predictions. Her physics background helps tremendously with the complex modeling needed to optimize the properties of the metals and metal oxides that she works with.

Engineering provides endless opportunities to put physics into action, Radcliffe says. "The most rewarding part of what I do is actually working with the material," she says. "Being surrounded by physics and chemistry as part of my job makes all those years studying for my degree worth it."

3 Understanding Employment Opportunities and What Those Careers Require

People who have studied physics are eminently well suited to contribute in a wide range of jobs, industries, and organizations. Thus, in considering the changes to physics education programs that will best prepare graduates for careers, it is necessary to be general, as the future's potential career paths are so broad and unpredictable. Additionally, in today's work world, individuals typically have several, potentially very different, jobs and positions during their careers. Thus, the education system needs to produce more flexible, more broadly-educated graduates than ever before.

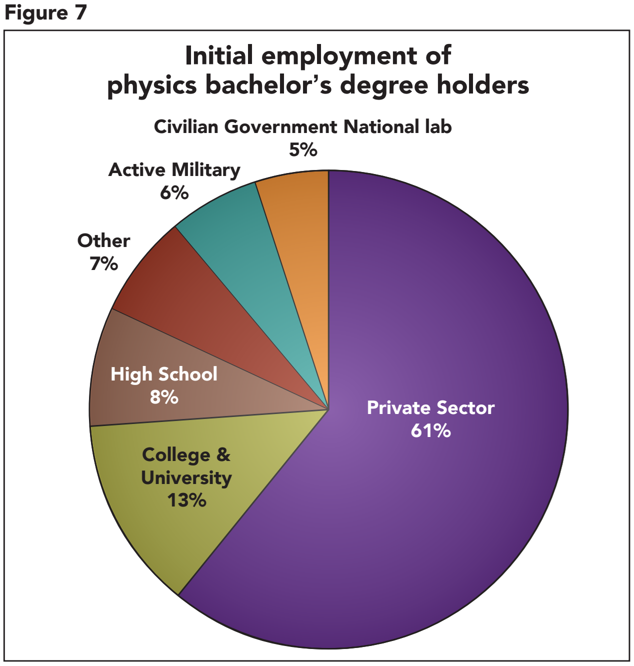
People trained in physics are well positioned to be innovators, and indeed often create great innovations in the process of conducting research, educating K-12 students, or working in the private sector. The physics community can benefit from promoting physicists as innovators of products, services, and processes in research, business, industry, and education. Emphasizing the innovation capabilities of physics students will reflect well on the discipline, provide resources to physics departments and programs, and better sell physics graduates as productive and creative employees.

Academic institutions, consulting groups, and economic development organizations have conducted many studies to determine what skills, knowledge, and attitudes will be needed by college graduates in the 21st century. They have studied the job market, industry demands, and the need for greater flexibility in the workforce. The studies summarized below address these topics, and recommend both general and specific areas that colleges and universities should be addressing to prepare graduates for diverse careers.

The two studies most relevant to physics graduates are the 2012 report by the Task Force on Teacher Education in Physics (T-TEP) [8] and the AIP/Society of Physics Students' (SPS) Career Pathways Project [41]. T-TEP found that, except for a few excellent programs, physics teacher preparation nationally is inefficient, incoherent, and unprepared to deal with the current and future needs of the nation's students. It recommended that physics departments recognize their responsibility for the professional preparation of physics teachers.

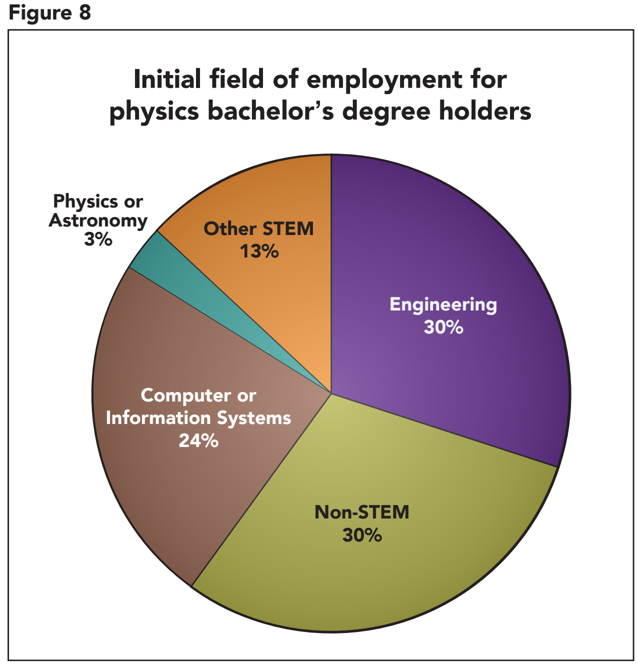
The Career Pathways Project emphasized that a large proportion of physics majors enter the workforce after completing their bachelor's degrees. By detailed study of departments that have a strong record of granting physics bachelor's degrees compared to other physics

Figure 7



AIP Statistical Research Center 2011-2012

Figure 8



AIP Statistical Research Center 2011-2012

Figure 7: Data does not include degree recipients from the three military academies (U.S. Naval Academy, U.S. Military Academy, U.S. Air Force Academy) Data includes two- and four-year colleges, universities, and university affiliated research institutes

Figure 8: STEM refers to natural science, technology, engineering, and mathematics

departments, and that are among the national leaders in terms of the fraction of their recent physics bachelor's degree recipients who entered the STEM workforce within a year of earning their degrees, the report identified 10 common features of physics departments that were exceptional in preparing graduates for careers. These included lab courses, research and outreach opportunities, and building a community of physics students and alumni [42].

In addition, studies by the Brookings Institution [43], the Adecco Group [44], the Burning Glass Consulting group [45], and the U.S. Bureau of Labor Statistics [46] have revealed a number of key features of national and global labor markets that are applicable to physics. These include:

- Demand for STEM-skilled workers is growing, such that there are fewer job applicants than job openings, especially in regions with otherwise low unemployment.
- A wide range of positions, especially those that are not necessarily in traditional technology areas, demand technical skills and a broad background—exactly the set of abilities possessed by physics graduates.

Recent reports and articles from the Daniel Group [47], the American Association of Colleges and Universities [48], *Forbes* [49], and *The Chronicle of Higher Education* [50] each identified a set of skills and competencies for graduates. Many skills are common among these studies, including:

- Working well in teams—especially with people different from yourself;
- Applying science and technology in real-world settings;
- Writing and speaking well;
- Thinking clearly about complex problems;
- Analyzing a problem to develop creative, innovative, and workable solutions, and implementing them;
- Taking into account the global contexts in which work is now done;
- Applying knowledge and skills in new settings;
- Using numbers and statistics to solve problems and communicate solutions;
- Acting with a strong sense of ethics and integrity;
- Convincing or influencing others;
- Planning, organizing, and prioritizing work.

A consensus emerges as well from reports issued by several scientific disciplines (see reports listed in Chapter 2). All of these reports indicate the need to update the undergraduate curriculum so that students will gain the knowledge, skills, and attitudes needed to succeed in 21st-century careers. In all cases, there was clear agreement that the current curriculum, in many ways, falls short of meeting the need.

In order to understand how well students graduating with a physics degree are prepared to work in non-academic careers, J-TUPP commissioned an interview study of recent physics graduates and their employers. This study, conducted in early 2015 by independent evaluator Dr. Rachel Scherr, involved interviews with 14 recent graduates with physics undergraduate degrees and five hiring managers directly responsible for hiring these types of employees. A full report is given in Appendix 2.

Most of the former physics majors had graduated between one and five years earlier, and all had been hired into positions in industry, technology, business, and the military. Former physics majors reported that useful disciplinary knowledge included electronics, electricity, and magnetism. Many mentioned the importance of problem solving, which appeared to have varied meanings for them. Some described it as the ability to break down a complex problem into simpler, solvable problems; some associated it with the ability to learn about new topics. Several participants specifically reported that their undergraduate experiences in research, teaching, and programming were important preparation for their current positions.

Former physics majors also identified areas in which they wished they had learned more before entering the workforce. In particular, they almost unanimously wished they had more programming skills and more experience in industrial and applied physics environments. In addition, former physics majors felt that if they had learned more about how to characterize and describe the marketable skills they acquired while pursuing their degree, they would have more easily found jobs.

The hiring managers interviewed were individuals who had made the decision to bring a physics graduate into their organization. They valued physics graduates for their broad training, technical and instrumental proficiency, and ability to solve ill-defined problems. When asked to identify skills that would make physics graduates more appealing, hiring managers asked for increased experience with research, more practice working with teams, and improved abilities to communicate through speaking and writing.

To help prepare majors for careers, the hiring managers encouraged physics departments to facilitate connections between companies and students, and to involve students in research early in their education through laboratory groups and internships. They further encouraged students to take advantage of internship and teaching opportunities, to learn about a variety of career opportunities, and to develop excellent writing skills.

It may be particularly important to note where former physics majors and hiring managers agreed on limitations in current undergraduate education. Both groups advocated for physics majors to gain more research and industry experience, programming skills, and knowledge of the marketability of the skills acquired during their degree programs.

Figure 9

Common Job Titles
of Physics Bachelor's Recipients

Computer Hardware and Software
- Software Engineer
- Programmer
- Web Developer
- IT Consultant
- Systems Analyst
- Technical Support Staff
- Analyst

Research and Technical
- Research Assistant
- Research Associate
- Research Technician
- Lab Technician
- Lab Assistant
- Accelerator Operator
- Physical Sciences Technician

Education
- High School Physics Teacher
- High School Science Teacher
- Middle School Science Teacher

Engineering
- Systems Engineer
- Electrical Engineer
- Design Engineer
- Mechanical Engineer
- Project Engineer
- Optical Engineer
- Manufacturing Engineer
- Laser Engineer
- Associate Engineer
- Technical Services Engineer
- Application Engineer
- Development Engineer
- Engineering Technician
- Field Engineer
- Process Engineer
- Process Technician
- Product Engineer
- Product Manager
- Research Engineer
- Test Engineer
- General Engineer

This list is composed of common job titles identified by an AIP Statistical Research Center survey of physics bachelor's degree graduates from the classes of 2009 and 2010.

Taking into account recommendations from organizations that have surveyed the job market, experiences of educational institutions reconsidering the goals and outcomes of their physics programs, survey data from physicists in a variety of careers, and input from industry, we conclude that physics graduates are well prepared to pursue a wide range of careers, and are sought for their flexibility, problem-solving skills, and exposure to a wide range of technologies. However, we also draw the following additional conclusions:

- The technical skills that physics graduates acquire should be expanded to address a wider and deeper knowledge of computational analysis tools, particularly industry-standard packages.
- Physics graduates would benefit from a broader set of experiences that engage them with industry-type work, such as internships and applied research projects.
- Physics graduates would benefit from closer connections between physics content and applications and innovation. Such experiences would also make the physics major attractive to more students.
- The addition of professional skills such as teamwork, communications, and basic business understanding to the undergraduate physics program would make physics graduates more successful in the workplace.
- A greater focus on the preparation of physics majors for careers in high school physics teaching would benefit physics programs and society at large.
- The physics community needs to better communicate the capabilities of physics graduates for a wide range of private-sector, government, and industrial positions, which requires that faculty members understand the private sector better.

These conclusions should also be viewed alongside programs in other disciplines, such as engineering, that do provide more career-related preparation for their students, and that are staffed by individuals who have greater experience in and understanding of both the private sector and the broad spectrum of opportunities available to graduates.

From our analysis of these reports naturally emerged a set of *learning goals* that fall into four distinct groupings, although there is of course overlap among learning goals within these groups and among the groups. The learning goals are described in the next chapter. Physics departments that have sought accreditation from ABET may note that there is a strong overlap between the learning goals we have identified and those specified as learning outcomes by the ABET Engineering Accreditation Commission [51].

4 Learning Goals to Support Diverse Career Directions

All physics departments seek to offer students opportunities to learn the things they will need to know and be able to do after they have completed the program. Constructing this curriculum has traditionally involved assembling a suite of courses and ensuring that all the vital physics topics are covered in one or more of them. In addition to specific physics content, physics programs have focused on developing technical skills important to the practice of physics, such as computation or the hands-on expertise that a good laboratory scientist must possess. A department may also take steps to ensure that its students develop the ability to communicate about physics in writing and speaking. Finally, faculty members seek to enculturate students into the norms of the discipline, guiding them to become independent thinkers with the ability to function effectively in any setting in which a physicist might find him- or herself.

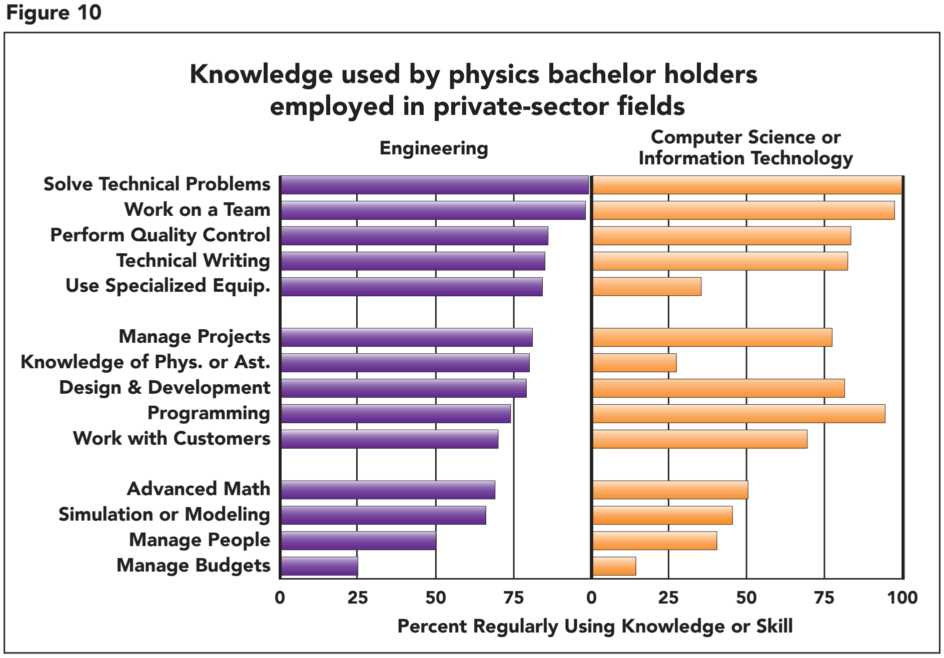
Traditionally, evaluating what a physics student will need to know, and thus what an undergraduate program should contain, has focused on preparation for graduate study and a career in academic physics. As we have noted earlier in this report, most students who graduate with a bachelor's degree in physics will follow different (and varied) paths that will require them to have additional knowledge and skills in order to be successful. However, unless physics faculty identify explicitly what specific knowledge and skills they want to help students acquire, it is impossible for them to verify that their program is providing the necessary opportunities. A well-articulated set of student learning goals and a means of measuring a program's success at providing opportunities for students to attain those goals are fundamental to the design of an effective degree program.

Although physics faculty members may not describe their program in terms of learning goals, they are mindful of *physics-specific knowledge* and *scientific and technical skills* they want their students to acquire, *communication skills* that are important to all scientists and others, and *professional and workplace skills* that they practice every day, often without being aware of them. Physics programs already incorporate elements intended to allow students to acquire at least some of the necessary knowledge, skills, and attitudes they will need in the workplace, whether or not as a result of explicitly articulated learning goals. However, a program is much more likely to meet the needs of its students if faculty members identify specific learning goals and the means to achieve them, and are accountable for these goals through systematic assessment.

Of the above-mentioned goals, faculty members have traditionally paid the closest attention to ensuring that students enrolled in their programs graduate with *physics-specific knowledge*, including core physics concepts (energy, fundamental nature of the physical world, conservation principles, etc.) that are generally taught in the canon of physics topics: mechanics, electricity and magnetism, thermodynamics and statistical mechanics, and quantum mechanics, and their application in areas such as optics, nuclear physics, condensed matter physics, and other subdisciplines. Physics students also gain skills in numerical, analytical, and experimental methods. It is less common, however, for physics programs to explicitly consider knowledge and skills associated with the application of physics in interdisciplinary contexts and in the wide variety of non-academic career settings in which graduates may find themselves.

A sound physics education will also include opportunities to acquire a

Figure 10



AIP Statistical Research Center

Figure 10: Percentages represent the physics bachelor's who chose "daily ," "weekly," or "monthly" on a four-point scale that also included "never or rarely.

variety of *scientific and technical skills* that are not necessarily specific to physics. These include problem solving; generic experimental skills in optics, vacuum technology, electronics, etc.; coding and software use; and data processing and analysis. While some aspects of these skills (especially certain kinds of problem solving, and electronics at the component level) are explicit components of traditional coursework, faculty often assume that other such skills will be acquired as part of advanced laboratory classes or through participation in research. However, unless departments explicitly adopt a goal of inculcating such skills and include specific activities to enable all students to acquire them, it is easy for many of these skills to fall through the cracks, or for students to fail to recognize which marketable skills they have acquired.

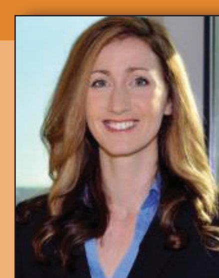
57% Percentage of physics bachelor's graduates who attend graduate or professional school

It is also rare for academic activities in physics, whether in a class or in research experiences, to include the use of industry-standard computational, design, analysis, and simulation software. This omission puts physics graduates at a disadvantage compared to their engineer-major peers, who are more likely to have had experience with such tools. Unless they write a senior thesis, undergraduates are also not often called upon to search the literature; read, analyze, evaluate, interpret, and cite technical articles; and make specific use of the scientific and engineering information therein, despite the fact that graduates are likely to be called upon to do so whether they pursue graduate study or enter the workforce.

Physics faculty members are well aware of graduates' need for *good communication skills*, but often the focus within a physics program is on the preparation of refereed publications. This is only one form of communication in the discipline, and one that may be of limited importance for many physics graduates. A physicist in an industrial or government setting is likely to need the ability to communicate science content and outcomes to individuals who may not be trained in science, including managers, sponsors, members of Congress, marketing personnel, technicians, and members of the public. Most physics programs include no specific opportunities to develop these kinds of communication skills. Adopting the goal of cultivating such skills and finding opportunities within the program to do so (perhaps in a symposium in which students present their research findings to a general audience, or during an outreach activity in which students communicate ideas to younger learners) can greatly benefit a program's students.

Physics faculty members routinely model for their students the *professional and workplace skills* that are necessary for success in academic physics. But a full degree program should also develop skills needed in the wide range of careers in industry, government, nongovernmental organizations, teaching, or self-employment that the program's graduates might choose to pursue. While it might appear that professional and workplace skills vary from one venue to another, there is a core set that applies in any position:

The Medical Student
Casey M. Dedeugd, Medical Student, University of Central Florida



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Casey Dedeugd received her bachelor's degree in physics from North Carolina State University in 2006. As an undergraduate, she was heavily involved in research, primarily in nanoscience. She synthesized and characterized monolayer films and measured electric dipoles using dielectric spectroscopy. These experiences led Dedeugd to pursue a master's degree in biomedical engineering from the University of Florida in Gainesville.

Her graduate research focused on imaging tumor microvessels in vivo using a unique hyperspectral imaging system that was able to determine the oxygen saturation of newly formed blood vessels within a cancerous tumor. This research aimed to improve therapies used to inhibit the formation of new blood vessels during tumor growth.

After receiving her master's degree, Dedeugd pursued a research opportunity at Duke University. She developed radiation-sensitive nanoparticles and learned other imaging techniques such as confocal microscopy and transmission electron microscopy. Simultaneously, she applied and was accepted into medical school at the University of Central Florida, to pursue her dream of becoming a physician-scientist. Dedeugd discovered that there is a lot of physics in medicine.

In medical school, Dedeugd continued to pursue research opportunities and worked on several retrospective studies. After graduating in May 2014, she began residency training in orthopedic surgery at the Mayo Clinic in Rochester, Minnesota.

problem solving, communication, management, working effectively with others, and dealing with constraints. Only some of these skills are explicitly fostered in most physics programs. Additionally, physics programs rarely help their students learn about career opportunities in physics, how to find a job (e.g., by developing résumé writing and interview skills), and how to assess one's skill set and its relevance to a job. This can make physics graduates' transitions to the workforce more challenging than necessary.

To assist departments in setting appropriate learning goals, we have compiled in the rest of this chapter a list of desired program outcomes that will help ensure graduates are prepared for career success. The outcomes are based on research undertaken by other committees and agencies, and on our own study of the issues, as described elsewhere in the report. Subsequent chapters of the report contain specific advice on how to achieve the learning goals and how to use them together with program assessment to improve program outcomes.

A department that wishes to enhance its program can do so by adopting the goals listed below, and may wish to add goals that are not mentioned here but that are tailored to its own program and students. The learning goals discussed below include some that must truly be *mastered*, as they are at the core of professional performance by physics graduates. There are other areas that are greatly beneficial to physics graduates, to which they should be *exposed*, and for which they must develop a basic appreciation and understanding. We draw this distinction not to suggest that the latter can be left out of the preparation of graduates, but rather to indicate that the level of detail and the expectations of performance in these latter areas are not as deep as for the former. Some of the learning goals are also provided with more detail than others, and some are easier to assess than others.

Even the act of adopting a specific learning goal and examining what it would mean to achieve it can bring significant benefit to a department. Indeed, a department that thinks consciously and intentionally about its learning goals is likely to see improved student outcomes more broadly.

Recommended learning goals for undergraduate physics programs

Upon completing an undergraduate physics program, ideally a graduate should be able to

A. Physics-Specific Knowledge

A.1. Demonstrate the ability to apply fundamental, crosscutting themes in physics, including conservation laws, symmetry, systems, models and their limitations, the particulate nature of matter, waves, interactions, and fields.

A.2. Demonstrate competency in applying basic laws of physics in classical and quantum mechanics, electricity and magnetism, thermodynamics and statistical mechanics and special relativity, and the applications of these laws in areas such as optics, condensed matter physics, and properties of materials.

A.3. Represent basic physics concepts in multiple ways, including mathematically (including through estimations), conceptually, verbally, pictorially, computationally, by simulation, and experimentally.

A.4. Solve problems that involve multiple areas of physics.

A.5. Solve multidisciplinary problems that link physics with other disciplines.

A.6. Demonstrate knowledge of how basic physics concepts are applied in modern technology and apply this knowledge to the solution of applied problems.

B. Scientific and Technical Skills

B.1. Solve complex, ambiguous problems in real-world contexts.

- B.1.a. Define and formulate the question or problem, i.e., ask the right question.
- B.1.b. Perform literature studies (print and online) to determine what is known about the problem and its context by locating, reading, analyzing, evaluating, interpreting, and citing technical articles; manage scientific and engineering information so that it is actionable.
- B.1.c. Perform trade studies [52] to identify the optimum technical solutions among a set of proposed viable solutions, based on applied experience.

B.1.d. Identify appropriate approaches to the question or problem, such as performing an experiment, performing a simulation, developing an analytical model, and making rough estimates based on specific strategies.

B.1.e. Develop one or more strategies to solve the problem and iteratively refine the approach.

B.1.f. Design an appropriate experiment or simulation to address the problem, taking into account precision, repeatability, and signal-to-noise ratio.

B.1.g. Engage in appropriate statistical analysis of results.

B.1.h. Identify resource needs for solving the problem and make decisions or recommendations for beginning or continuing a project based on the balance between opportunity cost and progress made.

B.2. Show how results obtained relate to the original problem, determine follow-on investigations, and place the results in a larger perspective.

B.3. Demonstrate *instrumentation competency*: competency in basic experimental technologies, including vacuum, electronics, optics, sensors, and data acquisition equipment. This includes basic experimental instrumentation abilities, such as knowing equipment limitations; understanding and using manuals and specifications; building, assembling, integrating, operating, troubleshooting, and repairing equipment; establishing interfaces between apparatus and computers; and calibrating laboratory instrumentation and equipment.

B.3.a. Use basic hand tools.

B.3.b. Interface apparatus to computers using tools such as LabVIEW, MatLab interface modules, and GBIP.

B.3.c. Use laboratory tools such as oscilloscopes, sensors, electronics, optics, vacuum systems, materials fabrication tools, signal digitizers, and signal analyzers.

B.3.d Make effective use of advanced analytical or process tools.

B.4. Demonstrate *software competency*: competency in learning and using industry-standard computational, design, analysis, and simulation software, and documenting the results obtained for a computation or design. Examples include:

B.4.a. General-purpose computational tools: Excel, MatLab, Mathematica, Maple

B.4.b. Optical computational tools: OpticStudio, CODE V, OSLO, TFCalc

B.4.c. Electrical computational tools: SPICE, PSPICE

B.4.d. Mechanical computational tools: SOLIDWORKS, Pro/ENGINEER

B.4.e. Physics computational tools: COMSOL Multiphysics

B.4.f. Educational simulation tools: Physlets, PhET Simulations

B.5. Demonstrate *coding competency*: competency in writing and executing software programs using a current software language to explore, simulate, or model physical phenomena.

B.6. Demonstrate *data analytics competency*: competency in analyzing data, including with statistical and uncertainty analysis; distinguishing between models; and presenting those results with appropriate tables and charts.

C. Communication Skills

C.1. Communicate with many different audiences from many different cultures and scientific backgrounds, understand each audience and its needs, and make the communication relevant and maximally impactful for that audience.

C.2. Obtain information and evaluate its accuracy and relevance through reading (print and online), listening, and discussing.

C.3. Articulate one's own state of understanding and be persuasive in communicating the worth of one's own ideas and those of others.

C.4. Communicate in writing about scientific and technical concepts concisely and completely, and revise writing to achieve grammatically-correct and logically-constructed arguments.

C.5. Organize and communicate ideas using words, mathematical equations, tables, graphs, pictures, animations, diagrams, and other visualization tools.

C.6. Teach a complex idea or method to others, use feedback to evaluate the learning achieved, and develop revised strategies for improved learning.

D. Professional/Workplace Skills

D.1. Work collegially and collaboratively in diverse, interdisciplinary teams both as a leader and as a member in pursuing a common goal.

D.2. Identify independently what must be understood, and learn it.

D.3. Generate new ideas.

D.4. Obtain knowledge about existing technology resources relevant for the task at hand. For example: How is the technology made? How does it work? What does it cost? Who tests it? What industries are affected by it? Where are the centers of these industries located? Where can the computational resources needed for the task be found? Which companies make the instrument needed for the experiment, and how do their products differ?

D.5. Demonstrate familiarity with basic workplace concepts. Examples include:
- D.5.a. Program and project management, including planning, scheduling, tracking progress, adapting, and working within constraints
- D.5.b. Budgeting and financial management
- D.5.c. Quality assessment and assurance
- D.5.d. Legal, regulatory, and ethical issues; compliance, intellectual property, and employment law, including issues of workplace behavior with regard to gender, race, sexual orientation, disability, etc.
- D.5.e. Effective management of difficult situations, including poor team performers, K-12 classrooms, irate customers, etc.
- D.5.f. Safety; working with and enhancing the safety culture in the workplace

D.6. Display awareness of regional and national career opportunities and pathways for physics graduates.

D.7. Demonstrate awareness of standard practices for effective résumés and job interviews, as well as professional appearance and behavior. Examples include:
- D.7.a. Assessment of one's skill set and its relevance to the job
- D.7.b. Assessment of one's strengths and weaknesses
- D.7.c. Interview preparation
- D.7.d. Appropriate and effective interview behavior, including appropriate attire and personal grooming
- D.7.e. Maintaining an informative professional online presence through LinkedIn, etc.

D.8. Demonstrate critical professional and life skills, including completing work on time, optimism, realism, time management, responsibility, respect, commitment, perseverance, independence, resourcefulness, integrity, ethical behavior, and cultural and social competence.

The Entrepreneur
Danielle Fong, Founder and Chief Scientist, LightSail Energy

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Danielle Fong skipped high school and earned her undergraduate physics degree from Dalhousie University in Canada. She moved on to Princeton for graduate school, where she hoped to develop nuclear fusion into the energy source of the future. But she found the pace too slow, so in 2007, at the age of 19, she left school and moved to Berkeley, California.

A year later, having made some connections, she and two friends founded a company called LightSail Energy. Their goal is to develop a new way to store energy, which is crucial because the major renewable, carbon-free energy sources—solar and wind power—are intermittent: The sun doesn't always shine, and the wind doesn't always blow. A year after launch, Fong and her colleagues secured initial funding for their venture.

Fong's company aims to store energy in large tanks of compressed air. Fong and her colleagues used thermodynamics to design an innovative technology that compresses air without overheating it, a problem that bedeviled previous efforts. Their process retains substantially more of the initial energy input than did previous technologies.

Fong is constantly solving hard problems for which physics comes in handy. "If you're interested and capable, physics is one of the best ways to work with problems," she says. "[Working at a startup company] is very social, and physics creates the language to communicate and to see the possibilities."

5 Providing Opportunities for Students to Meet Learning Goals

The strategies available for helping students achieve a department's learning goals vary widely in the level of commitment required. Some departments may be ready to redesign their programs entirely; others may choose to infuse the development of new skills into their current course offerings; and still others may rely primarily on enhanced co-curricular activities. The strategies that departments adopt or develop will depend significantly on local conditions, including the resources available, the size and aspirations of the student body, industries in the region, etc. There is no one-size-fits-all approach. However, most of the learning goals we have identified can be pursued through more than one channel. Below we present a range of suggestions that are intended to provide a starting point. Illustrative examples are included, many of which are discussed in greater detail in the case studies included in Appendix 1 of this report.

A. Overview

The learning goals associated with *physics knowledge* are probably most familiar to faculty in physics departments, and will generally be addressed in standard courses. However, the content of virtually any of these courses can be related to career-relevant applications (even general relativity has a practical use in GPS technology), while maintaining a focus on fundamentals. Additionally, updating these courses in accordance with the best available evidence from education research will improve student outcomes. The research literature also provides many resources for assessing student progress toward physics-specific learning goals, as well as strategies for achieving overarching goals related to increasing student persistence, improving equity, etc.

Faculty can cultivate students' *scientific and technical skills* by modifying existing courses or labs to incorporate the application of physics principles to industrial processes and commercial devices, without reducing the learning of fundamental physics content. Commercial products can be incorporated into laboratory courses to help ensure that students are familiar with industry-standard software packages.

Students' *communication skills* can also be addressed at many points in the curriculum. For example, students can produce oral reports on topics relevant to a standard class or as part of a seminar. General writing and editing skills can be cultivated in classes taught in departments such as English or communications, while science-specific writing skills can be cultivated in science classes via lab or research reports.

Workplace and professional skills can also be developed in existing courses, or in co-op or internship experiences. For example, lab courses can promote the ability to work effectively in groups. Basic business concepts can be incorporated through courses taught in science or engineering departments, or in business schools. Finally, to conduct a successful job search, many students will need not only résumé-writing and interview skills, but also practice describing their skill sets and articulating what they have to offer to potential employers. Departmental activities combined with the services of university-wide career placement offices can help give students these skills.

In addition to promoting these four broad categories of learning goals, the strategies discussed below will help departments raise awareness and increase the status among students and faculty of the range of career options available to physics graduates.

B. Develop new opportunities through partnerships with other units on campus and with local employers

Many of the learning goals identified in this report can be pursued through collaborative efforts involving the physics department, other units on campus, and employers of physics graduates. These efforts include immersive experiences in the workplace through co-op stages or internships, or intensive interdisciplinary programs on themes such as innovation and entrepreneurship. While perhaps the most demanding of the various strategies discussed here, these options provide unmatched opportunities for students to pursue multiple learning goals in a single coherent program.

1. Establish internships and/or co-op opportunities

While physics students are often directed to Research Experiences for Undergraduates (REU) programs in traditional academic research laboratories, many would benefit as much or more from an intensive experience in an industrial or commercial environment. Internships or co-op stages, which have been used in engineering for decades, allow students to spend a significant amount of time in an off-campus workplace. In addition to providing direct exposure to product development and manufacturing, internships can help students focus on nontechnical aspects of science, such as documentation, communication, and business development [53]. Students placed at scientific service companies will be exposed to proposal preparation, project cost tracking, corporate structures, and project execution. Technology transfer offices at national laboratories offer opportunities to learn about patents, licensing, and commercialization. Internships often lead to job opportunities for students, and students interested in a particular industry would do well to intern with a leading firm.

Students considering teaching careers can also benefit from internships. For example, a department can arrange for students to visit, and ultimately assist, a local high school master teacher. Such individuals can often be identified through the university's school of education, or by polling physics majors to identify excellent local high school teachers. Establishing a relationship with practicing teachers can provide departments with multiple benefits, including potential pipelines of new students, a better understanding of challenges faced by physics teachers, and routes to providing assistance to these individuals.

To ensure the success of internship or co-op experiences, faculty should define specific desired student outcomes and reach agreement with the internship sponsor about how the experience will lead to those outcomes. In designing programs, departments should work closely with other campus groups that may have relevant connections and expertise, such as career services offices, engineering departments, and business schools. These linkages may also provide opportunities that may be more diverse than traditional physics positions—exactly the type of experience that will expose students to the full breadth of applications of their knowledge and expertise.Also critical to the success of co-op or internship programs are stable funding mechanisms. Employers are more likely to feel that a program's benefits are sufficient to rationalize the expense if the relationships with the academic partner are stable and long-term.

42% Percentage of physics bachelor's graduates who enter the workforce directly

Develop co-op experiences. Kettering University in Flint, Michigan, originally founded to support the automotive industry, offers a variety of programs in applied sciences, including applied physics and engineering physics. Every student is required to participate in a sequence of co-op experiences in addition to their on-campus coursework. The curricular structure is spread over five years, and results in students who have obtained real industrial experience and are often hired by one of the firms at which they have participated in a co-op.

2. Establish interdisciplinary programs

Given that many departments (especially other STEM departments) will share with physics departments many broad goals for their students, interdisciplinary programs may provide an efficient way to capitalize on expertise not found in the physics departments. Programs that offer a minor or certificate may be especially appealing to students. Moreover, the opportunity to work with students from a variety of majors can provide an excellent opportunity to develop professional and workplace skills.

Interdisciplinary programs are especially well suited to introducing students to key principles and practices related to entrepreneurship and innovation. These programs can be staffed by individuals who have the academic, industrial, and economic development background to link students and departments with opportunities in the private sector. The goals of these programs are to create graduates who are particularly skilled in innovation and the entrepreneurial mindset, with grounding in a breadth of professional and business skills applicable in any career pathway.

Develop interdisciplinary programs to support innovation and entrepreneurship. The *ScienceWorks* program at Carthage College in Kenosha, Wisconsin, brings professional skills to students majoring in the sciences (although the program draws students from across campus). The program comprises a two-semester required course sequence, an elective course chosen from a list of appropriate supplementary topics, and a two-semester technology-based business plan project. Partnerships with regional economic development organizations, linkages with industries, an advisory board of executives and legal and financial experts, and faculty with experience in corporate management and business startups and operation are key components that add value to the program for students.

Partner with national programs that promote innovation and entrepreneurship. VentureWell (formerly the National Collegiate and Innovators Alliance), and Stanford University together operate EpiCenter. Funded by NSF, EpiCenter brings innovation and entrepreneurship education to partner schools across the country, primarily through the Pathways to Innovation Program. While aimed primarily at engineering programs, Pathways involves multiple departments on each campus in creating curricular elements and implementing co-curricular experiences that provide participating students with experience in innovation and entrepreneurship.

Many of the benefits of interdisciplinary programs can be achieved at a more modest scale through the development of new courses that formally integrate physics content with other disciplines. These can be cross-listed between two departments and/or team-taught.

C. Redesign the major

Within the department, many of the learning goals identified in this report can be pursued through changes to degree requirements, whether through increased flexibility that allows students (in partnership with advisors) to plan programs appropriate for their chosen career paths, or through formal tracks that incorporate carefully-chosen electives. Greater flexibility in the major will also help motivated students pursue a minor in a related discipline, such as computer science, education, or business. Broad learning goals such as those associated with professional or communication skills can be infused into the curriculum at multiple points or addressed coherently in a single integrative experience such as a capstone course.

1. Make the major more flexible

Making the physics major more flexible can allow students to tailor their degree programs to specific career paths. However, to do this, faculty may need to rethink the traditional physics "canon." For example, some students may be better served by replacing some traditional core physics courses with physics electives that address practical topics with industrial applications, such as condensed matter physics and optics. Some traditional core courses could also be with replaced with courses from disciplines such as engineering, biology, statistics, computer science, speech, business, technical and creative writing, and philosophy (especially ethics/reasoning skills).

For students pursuing K-12 teaching, courses in physics pedagogy are critical, and students are unlikely to learn about critical physics-specific teaching issues and methods outside the physics department. Given that everyone acts as a teacher in many contexts (e.g., helping one's boss understand a new technique, helping a new employee learn a particular type of experimental measurement.), such courses may be valuable even for students not going into K-12 classrooms.

Some departments offer both B.S. and B.A. degrees; in such cases, the latter is typically intended to promote a broader education by requiring fewer physics courses.

Figure 11

Most common majors combined with physics

- **Mathematics**
- **Engineering**
- **Astronomy & Astrophysics**
- **Chemistry**
- **Music & Fine Arts**
- **Computer & Information Sciences**
- **Education & Teaching Certification**
- **Economics**
- **Philosophy & Theology**
- **Biology**
- **History & Political Science**
- **Geosciences**

One-third of physics bachelors graduate with double majors

AIP Statistical Research Center.

2. Establish career-relevant "tracks"

A number of institutions have implemented new tracks, concentrations, or degree programs to better prepare students for diverse careers, especially ones that are relevant in the region in which the institution is located. In some cases, students can select from among several formal tracks or concentrations that emphasize applications, physics education, medical imaging, etc., which may involve coursework in several units on campus. In other cases, the "tracks" are unofficial, and constitute a recommended package of electives designed to offer a coherent experience. Dual-degree programs (3-2 or 4-1 programs) are another mechanism allowing students to combine a solid grounding in physics with a career-related specialization such as engineering.

Provide informal "concentrations" to guide students. At Carthage College, the formal requirements for the physics major are similar to those of most other physics departments, but the program offers several concentrations, most of which are not formal tracks (i.e., they will not show up on a transcript). Rather, the department provides recommended sets of courses for different career tracks, such as graduate school or teaching physics at the secondary level.

Partner with other on-campus units to develop formal degree tracks. For a small department (13 faculty), the University of Wisconsin-La Crosse (UW-La Crosse) physics department offers a wide array of degree options, including astronomy, biomedical, business, computational, optics, physics education, a second major in general science education, and dual-degree programs in engineering and physical therapy. Students can easily switch between different tracks, since various mathematical backgrounds are accommodated. (Both the algebra-based and calculus-based introductory physics courses count toward the major.) The dual-degree 3-2 engineering program is particularly popular, since students are more familiar with the career options in engineering. The department also leverages the university's strong physical therapy program to offer both a biomedical concentration in physics and a dual-degree physics-physical therapy program.

18% Percentage of physics bachelor's graduates who work in engineering

Tracks designed for students preparing to become physics teachers should be informed by state licensing standards. Physics departments should ensure that all the physics courses in such a program are necessary and appropriate. The rigor of the track should derive not only from physics content but also from a sequence of courses that focus on the teaching and learning of physics.

Partner with your institution's education school to establish a track for prospective teachers. At Seattle Pacific University, physics students who graduate from the physics teacher preparation program earn a physics degree and a secondary science teaching certificate with an endorsement in physics in a four-year program. The certification program consists of courses in educational psychology, general science methods, and assessment. Future teachers can gain early teaching experience through the undergraduate Learning Assistant program, which facilitates peer learning among students.

3. Encourage capstone experiences that are career relevant

Many physics programs require a capstone activity: a thesis, senior seminar, or other integrating experience. In many departments, students will intern in a research laboratory and write up their work, conduct book research on a historical or major scientific breakthrough, or carry out a model experiment of their own under faculty guidance. These activities could be tailored to address one or more of the above-mentioned learning goals. For example, having students use commercial graphics software packages to analyze data and prepare charts and use CAD software for diagrams and design are ways to bring industry-standard skills into an existing academic course or program.

These efforts will be most successful if the mechanisms for promoting broad learning goals are common across all capstone experi-

The Wall Street Analyst
Amy Rodgers, Sales and Trading Analyst, Citigroup Institutional Clients Group

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"I knew even before starting college that I wanted to study physics," Amy Rodgers says. "What I didn't know was just how much a degree in physics would open career doors for me."

While Rodgers enjoyed learning theory during her undergraduate years at the University of Virginia in Charlottesville, the applications of physics really captivated her. The summer after her third year, Rodgers studied international economics at the University of Oxford. She realized that calculus is the second language of the physics major, and her understanding of underlying mathematical concepts made the finance learning curve quickly scalable.

Rodgers wanted to use her technical and analytical abilities in a dynamic and fast-paced setting, so she went to work on Wall Street. Her physics training taught her to tackle complex projects in an unbiased and analytical manner, rather than be intimidated by them. It also taught her to solve seemingly complicated problems by breaking them down into their constituent variables. She quickly learned how to analyze equities, derivatives, rates, and fixed-income securities.

Rodgers now works as a sales and trading analyst at the Citigroup Institutional Clients Group. Her job involves understanding and creating metrics around investment trends in the hedge fund industry.

Rodgers has met many other finance professionals who came from physics. "I didn't realize just how many hidden physicists were hiding out on Wall Street!" she says.

ences, and individual faculty are not solely responsible for ensuring that these goals are met. For example, requiring students to orally present their work, regardless of which research lab they work in or the type of thesis project they undertake, can help cultivate communication skills.

> **Organize the capstone course around program-level learning goals.** At UW-La Crosse, the development of program-wide learning goals led the physics faculty to realize that they needed a course that would allow them to assess student mastery of these goals. They developed a capstone course organized around these program-level goals. Students are required to research a topic and prepare a 20-minute technical presentation, to write a 500-word article aimed at a general audience, and to complete several paper-based assessments (such as a math skills test, a test in their major field, and a Fermi question test [54]).

Departments can also broaden their definitions of what counts as a capstone experience. Linking students with research experiences in other departments can give students exposure to a wider range of areas where they can apply their abilities and interests. Some may appear obvious (chemistry, neuroscience, etc.), but areas such as theater (e.g., lighting) and the arts (e.g., ceramic processing and color mixing) also involve a lot of physics, and students may benefit greatly from applying their skills in these diverse settings.

For students interested in teaching careers, a capstone project could include creating a lesson plan and assessments for teaching a topic at the K-12 level. Teaching opportunities within the department, through "Learning Assistant" programs, (see Chapter 5) for example, could also count. These early teaching experiences expose students to the rewards and challenges of teaching, allowing students to consider physics teaching as a career. The communication and pedagogical skills developed by Learning Assistants are equally valuable in non-teaching careers, since the ability to explain physics and other technical subjects is critical in many jobs. Moreover, these experiences will be valuable for those who end up in academia.

D. Design or redesign courses

Redesigning the physics major from the bottom up, as described above, yields opportunities to fully integrate career-related learning goals into the undergraduate program. However, we recognize that redesign of a complex university program such as a physics major is often a slow process, in which faculty leading the effort must consult the various stakeholders (including other department faculty, students, deans, and upper administration) and develop plans to address concerns and constraints, such as the number of credit hours required. Even when changes are entirely within the department but involve making connections among several courses that have linked prerequisites or require faculty cooperation, change may be slow. In this section we highlight changes that may involve fewer structural or administrative barriers.

18% Percentage of physics bachelor's graduates who work in non-STEM jobs

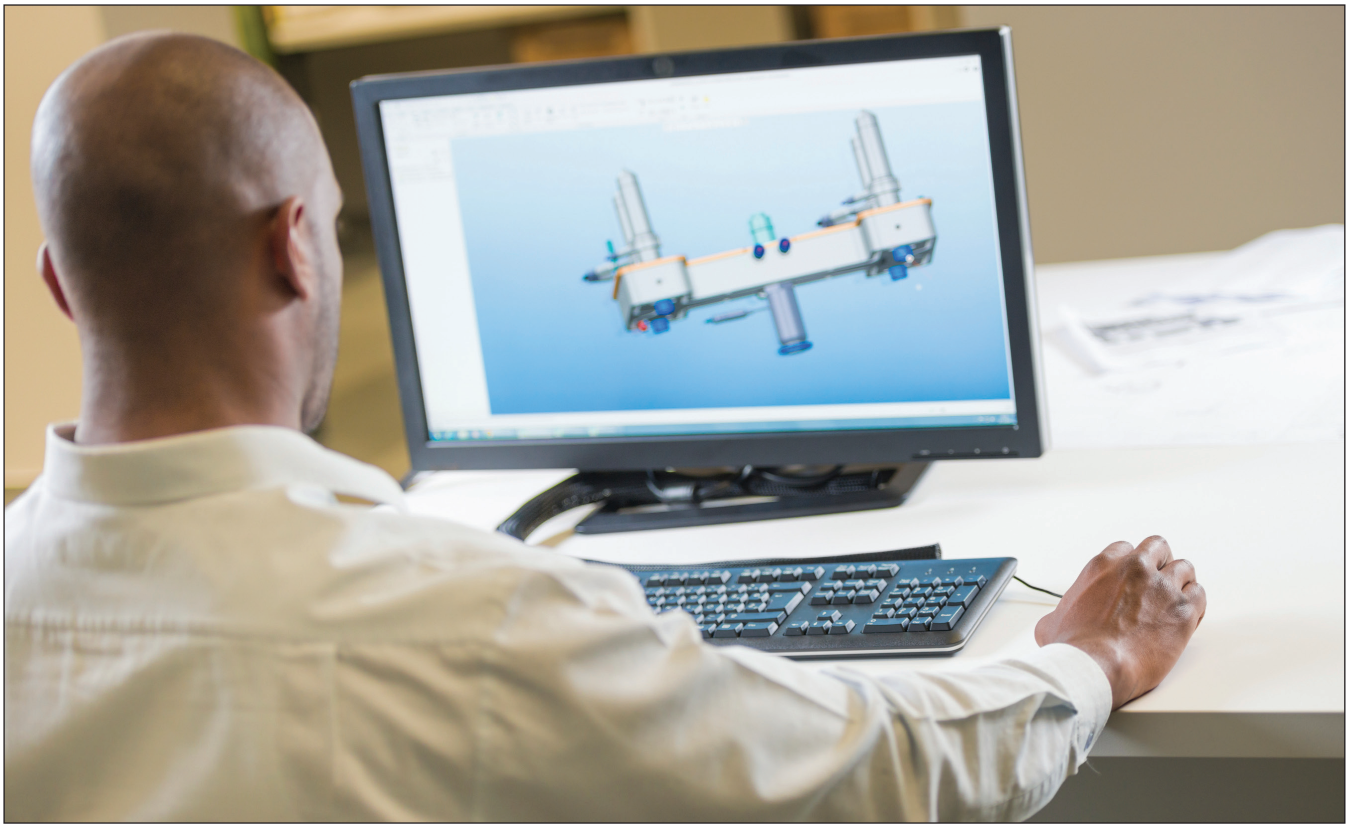
1. Emphasize applications in standard courses

Introductory physics courses typically include laboratory exercises meant to elucidate specific physics principles (e.g., parallel versus series spring constants, or the effective resistance of a network). These experiments, and those in many advanced lab courses, can be redesigned to incorporate applied physics elements, perhaps in a commercial context, while still addressing the core physics principles that students are expected to learn.

> **Use commercial applications in laboratory courses to illustrate fundamental concepts.** In an introductory course, the (simulated) use of reaction wheels to steer spacecraft can serve as an application of angular momentum conservation. In a modern physics course, the traditional Michelson interferometer can be linked to ring-laser gyros, which form the cores of inertial measurement units on many systems, including aircraft. In an optics course, the dense wavelength division multiplexing filters used in communications to separate bands of different wavelength all traveling on a single fiber can be used as a model for interference coatings, spectral measurements, etc.

Homework problems, especially in upper-division courses, can also involve real-world and cross-disciplinary applications. Students can be asked to take basic problems they are solving and investigate relevant patents or industrial and applied uses for the physics involved, and perhaps report these in short papers or class presentations.

A more substantial change would be to organize courses around applications. For example, a course designed around solar cells can encompass quantum mechanics, thermal physics, optics, electricity and magnetism, solid state physics, etc., either concentrating on one of these subdisciplines or covering more than one in an integrated fashion. It is worth keeping in mind that not all applications of physics knowledge are industrial. A course structured around the teaching of physics can help everyone, not just future teachers, think about how people understand new concepts while developing their own understandings of these concepts. Courses focused on biophysical and biomedical applications can be valuable for students who pursue careers in medical fields. Physics also plays a central role in understanding challenges and solutions associated with clean energy, clean water, and other environmental challenges.



2. Infuse career-relevant technical skills into laboratory courses

If they do not already, laboratory exercises can incorporate industry-standard software packages. Instructors can develop their own familiarity with these tools (as many faculty members have done with MatLab, LabView, SOLIDWORKS, and the like in their research) by exploring readily-available free or low-cost versions of the software. Data analyses can be conducted using software tools, including Excel, MathCAD, Mathematica, etc. Electronics courses can incorporate not only the standard analog and digital circuits, but also newer technologies such as Arduino and Raspberry Pi. Advanced labs can be coupled with short workshops and/or online courses to allow students to obtain training credentials in specialized software packages and equipment.

Use free versions of industry-standard software packages. Students can learn Optics Software for Layout and Optimization (OSLO), an imaging systems design package available in a free student version, in an optics course, to model the lens-and-mirror systems they study in the laboratory component. Similarly, students can design experiments and document setups using CAD software, thus developing software and industry skills as part of a regular laboratory activity. Many free CAD packages are available, including LibreCAD and FreeCAD; Google SketchUp is another option.

Introduce problem definition and project management skills into the lab experience. Open-ended laboratory projects conducted by teams can be a means to build valuable professional and workplace skills. At Carthage College, student-generated case-study experiments are part of the introductory calculus-based sequence. Student teams identify a phenomenon and design an experiment to examine it, conduct the experiment, and report results. For example, one group studied car crashes by using strobe photography of weights falling on aluminum soda cans. These open-ended, student-generated experiments effectively engaged students in learning how physics concepts apply in the real world and in forming and executing team-based projects.

Provide authentic research experiences within advanced lab courses. To provide students with professional research skills, faculty at the University of California, Davis (UC Davis) redesigned their Advanced Lab course to focus on two in-depth investigations. Students complete two experiments of their choice, including writing a *Physical Review*-style article that is then critiqued and resubmitted. The writing assignments are such a significant portion of the course that the course fulfills a university writing requirement. The course also includes a set of shorter labs that incorporate troubleshooting skills to help students build up to more intensive investigations.

3. Incorporate communication and professional skills throughout the curriculum

Faculty can provide students multiple opportunities in different contexts to cultivate communication and professional skills. This approach will be most effective if faculty adopt a consistent approach to coaching and feedback. This approach can be formalized through establishment of a "communicating in the discipline" requirement (which may also satisfy a campus requirement). Students can be provided with opportunities to complete the requirements in existing settings such as lab courses, capstone courses, or student research presentation events. Having students give presentations to *outside* reviewers (e.g., a panel of visitors) is an excellent tool for honing presentation skills to varied audiences.

Infuse communication skills throughout the curriculum. In upper-level courses at UC Davis, students write short papers about current research. Students survey the literature and use "research wikis" to provide images, video, and formal references to present a study in an online format that simulates an authentic peer-reviewed research experience. In the department's Advanced Lab course, students are required to produce and revise two *Physical Review*-style papers. Lastly, the university's Physics Club hosts talks by students about their research.

Develop disciplinary courses to address technical and professional skills. Florida State University in Tallahassee requires that all students fulfill oral communication and computing competencies. While general courses are available to fulfill this requirement (for example, courses in the College of Communication and Information), physics department faculty felt that these skills were best developed within the discipline itself. Thus, physics faculty created two courses, Communicating Physics and Computational Physics, in which students learn to give talks about physics and use computer tools to extract information from large data sets. These skills in turn prepare students well for a variety of STEM careers.

4. Use general education requirements to foster communication and professional skills

Requirements outside the physics major (e.g., "general education" requirements) can also be used to meet many of the above-mentioned learning goals. By guiding students to enroll in appropriate business, economics, law, ethics, organizational effectiveness, graphic design, and other courses that fulfill these requirements, it may be possible to achieve some of the learning outcomes without adding to the physics program or increasing the academic load the students bear. For example, technical writing and presentation courses may fulfill requirements in basic communications skills common to undergraduates in all programs, and will benefit students in almost any sector of the work world.

5. Develop seminars or courses that focus on career preparation

Physics bachelor's students often have difficulty marketing themselves because they do not have a readily-identifiable set of specific skills that are relevant to potential jobs. Physics majors must learn how to extract specific skills they learned during their studies and articulate them in ways that are easily understood by employers, especially those in sectors not traditionally associated with physics. The AAPT Career Center website [55] and the AIP/SPS Careers Toolbox for Undergraduate Physics Students [56] are useful resources that can help students understand and describe how their skills could benefit employers. A number of physics departments have also developed courses or seminars that provide practical guidance in job searches, résumé preparation, etc., and educate students about career options and the types of preparation they demand. Ideally, these seminars help students understand the regional employment landscape.

15% Percentage of physics bachelor's graduates who work in computer or information systems

Promote awareness of career options early in the major. At Florida State University, physics majors must enroll in a one-credit seminar, Discovering Physics, in which they learn about career options and the skills of professional physicists. As part of that course, students must write a résumé and have it critiqued at the university's career center. This makes use of an important campus resource and helps students build a strong résumé for future use.

Embed exploration of careers into the first-year course. Physics faculty at St. Mary's College of Maryland have developed a set of weekly assignments related to careers that are incorporated into the third semester of the introductory course sequence. Students explore careers and graduate programs, find summer research opportunities, draft and revise a résumé, and learn about networking.

6. Develop courses that feature service learning or Academic Civic Engagement

Academic Civic Engagement [57] is an approach to embedding learning in a community context, often involving collaboration with community partners (local government, nonprofits, community groups, local business, etc.) on a common project. In addition to academic content, students can gain valuable professional skills and contacts.

E. Leverage co-curricular activities

Co-curricular activities are generally underutilized for providing directed, intentional learning experiences. However, they may allow departments relatively simple ways to offer career readiness opportunities for students.

1. Host talks and other events that feature physics graduates in diverse careers

Students respond well to "experts," i.e., individuals who live and breathe the fields in which they have interest. Regularly scheduled events, including seminars and colloquia, that connect students and other department members with physicists from the applied and industrial worlds can promote many learning goals. Inviting non-academic physicists to talk about their work, the application of physics in their fields, their career trajectories, and the opportunities available in commercial and applied environments can expose students to a greater range of professional opportunities, and assist faculty in identifying possible research opportunities and industrial collaborations.

It is important to "coach" incoming speakers on the particular topics and information you hope they will address during their talks, to ensure that the learning goals you have set for students are achieved. Colloquium speakers can also be invited to meet directly with students (for example, at an SPS chapter meeting) and with faculty.

In addition to traditional research talks, events can also connect current students with physics graduates who work in policy, sales, patent law, teaching, and other fields. Finding local physics teachers to discuss their work should be possible for most departments. Such visits can provide students with a valuable perspective on the rewards and challenges of teaching. Many students underestimate the average compensation that high school teachers receive, and are also not aware of the significant intellectual challenges inherent in teaching. The opportunity to interact with a current high school teacher can allow students to more accurately assess their own interest in teaching.

2. Engage alumni/ae

Alumni/ae can serve as especially good role models, and are generally happy to visit their home campuses and share their experience with current students. In addition to inviting alumni/ae to speak about their work, engaging them as part of an advisory board or panel can ensure that the department's career advice is current and appropriate, and can also connect the department with potential internship and job opportunities for students. Keeping in touch with alumni/ae may be challenging, but undergraduates can often track down graduates through online searches, LinkedIn, etc. Many alumni/ae may appreciate being contacted directly by current students.

The Writer
Clara Moskowitz, Science Writer and Editor, *Scientific American*

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Clara Moskowitz grew up dreaming of being a scientist. She went to space camp and attended Wesleyan University in Middletown, Connecticut, where she used the telescope to collect and analyze data, and presented her research at conferences. Eventually she realized that while she loved learning about physics and astronomy, she didn't so much love actually doing the research.

So she found another way to keep learning about science: write about people who love to do research, in a way that non-scientists can understand. Moskowitz's first full-time job was with the online publication Space.com, where she covered NASA's space shuttle missions. This meant flying to Florida for each launch, then to Houston for the missions themselves. Sometimes she would wake up in the middle of the night to cover a spacewalk or experiment.

Now at *Scientific American*, Moskowitz spends less time writing and more time editing other people's writing. For example, she recently assigned and edited an essay by Brian Greene, one of her childhood writer heroes. She also makes podcasts and helps design and put together magazine issues.

Moskowitz says her background in physics helps greatly as she seeks to make science accessible to others. "It's tough material," she says. "I need to read journal articles and abstracts and know what they're about. If I didn't have my physics degree there's no way that would be possible."

Keep in touch with alumni/ae. The physics department at St. Mary's College of Maryland keeps data on its alumni/ae, including year of degree, type of career path, and current and past positions. The department tracks this information through the alumni/ae office as well as social media and personal communications. This information has proven valuable in tailoring the degree program to students' needs. The department also offers a half-day alumni/ae and student gathering, including panel discussions and networking. This event provides an opportunity for alumni/ae, faculty, and students to connect, and for students and faculty to learn about career paths. The event serves as a recruiting tool for the department, and is viewed favorably by the administration.

$55,000 Median starting salary of physics bachelor's graduates in a private-sector STEM job

3. Support student organizations

Meetings of student organizations such as the Society of Physics Students and local physics clubs are perfect venues at which to deliver career preparatory material to students. Invited speakers, visits from campus career center representatives, visits to local businesses or economic development organizations, etc., are easily coordinated. Such activities are likely to attract students beyond the SPS membership, and may result in recruiting new students into physics. SPS chapters and physics clubs should be encouraged to engage in outreach activities, as a means to teach communication skills, project management and scheduling, team building, etc.

Support student-led learning communities. A new cadre of student-led groups focused on equity has started to make a positive impact on physics departments by supporting student learning communities, helping students develop professional skills, and empowering students to take ownership of their education. The Compass Project at the University of California, Berkeley [58], established in 2007, is the forerunner of a new national network of such groups. The NSF-funded Access Network is helping spread this model to other institutions.

Departments can encourage the formation of student-led groups by indicating willingness to provide financial and logistical support. Compass aims to create a supportive community for students in the physical sciences with a particular focus on traditionally underrepresented groups. Current programs include a course for transfer students, mentoring for undergraduates by graduate students, and a two-week summer program for incoming freshmen that focuses on science process skills and cohort-building through classes, field trips, and study sessions. Student project leaders develop valuable professional skills such as organizing and mentoring.

4. Engage undergraduates in outreach

Outreach and informal learning experiences can benefit the students doing the outreach activities as well as the intended audiences. Students learn public communication and performance skills that can help them sell projects, products, or ideas. Young people—especially middle and elementary school students—see young adults who can serve as more-accessible role models than older professors, or even as potential mentors to help them develop as scientists or engineers. An added benefit is that this activity can also serve as a recruitment tool for the department. Programs such as the UTeach model from the University of Texas at Austin [59] also provide a framework for engaging students in outreach aimed at K-12 schools. The experience can help even students who are not interested in teaching careers learn valuable professional skills.

Support a strong outreach program. The physics department at Florida State University is considered a national leader in public outreach. The department runs a Saturday Morning Physics program, an open house (the "Flying Circus of Physics"), planetarium shows, faculty presentations at K-12 schools, and an annual summer camp for teachers. These activities play important roles in long-term recruiting, keeping faculty connected to the interests and skills of K-12 students and teachers, and providing important skill-building opportunities for undergraduate students involved in the programs.

5. Engage undergraduates in teaching

In many departments, undergraduates play a vital role in teaching. In addition to familiarizing students with teaching careers, teaching responsibilities can provide more general career preparation by helping students refine their communication skills and develop good habits such as arriving promptly for scheduled class sessions, meeting grading deadlines, and providing constructive feedback.

Launch a Learning Assistant program. Unlike graduate teaching assistants who help faculty teach, Learning Assistants (LAs) are undergraduates who facilitate active learning among their peers. LAs can circulate in the classroom during clicker questions and other active learning activities, help staff recitations that use interactive learning techniques, and provide additional tutoring for students.

In the program at the University of Colorado Boulder, where the LA concept originated, participants take a one-semester pedagogy course and get a stipend or course credit for their work. This program has multiple benefits: Students in courses that include LAs learn more, faculty are better able to manage active-learning environments, and LAs help faculty learn more about their students' struggles. The LAs themselves learn their physics better, learn how to teach, learn professional skills (e.g., communication, meeting deadlines, and timeliness), and are more likely to pursue careers in education. [60]

6. Engage undergraduates in other employment within the department

Many physics departments have employment opportunities that can help students develop valuable technical and professional skills, including assisting in machine and electronic shops, building and maintaining laboratory and lecture demonstration apparatus, assisting with library or office duties, etc.

7. Organize site visits

Site visits, whether as part of a course or organized through the campus physics club or SPS chapter, can link students with a wide range of off-campus organizations. A broad approach should be taken to engage organizations that may seem far afield from physics, as physics plays a significant role in virtually every industry and trade. As with colloquium speakers and internship sponsors, it is important to prep the visit host on the types of information and demonstration that will be beneficial to the students, linked to the learning goals that are being addressed.

8. Take advantage of campus career services offices

Every campus has an office dedicated to helping students find internships and jobs. Most of these offices are happy to provide training in career preparation, résumé writing, interviewing, proper dress, etc. Often career services staff need guidance on professional skills or areas that are particularly important for physics students, but they can also bring in a range of expertise that a department may not have on its own. Frequently these offices conduct organized programs such as interview workshops, formal dinners, and dress-for-success presentations, which physics students can be asked or assigned to attend. Undergraduate physics majors should become familiar with these services early, preferably before completing their junior year. At this point they will begin crafting their résumés and learning more about professional skills that many employers desire.

> **Introduce students to the career office early.** At St. Mary's College of Maryland, all first-year students must write a résumé, and then use the campus's career services office to help revise and improve that résumé. This reduces the burden on instructors, while also building valuable career skills for students and introducing them to career services early in their college careers.

9. Take advantage of cross-campus events

Nearly every department on campus has a colloquium or speaker series. Attendance (encouraged or assigned) at talks given in disciplines other than physics, including business, education, and other technical disciplines (e.g., neuroscience or mechanical engineering), can help students and faculty obtain a deeper appreciation of the careers available to physics graduates.

10. Take advantage of regional, national, and international events and resources

Local small business development centers, Rotary clubs, chambers of commerce, and economic development agencies all host events that attract business and industry leaders. Attendance at these events can expose students and faculty to a wide range of job and networking opportunities, and opportunities for joint projects.

Similarly, students should engage with other organizations, including professional societies, which often offer low membership rates and other perks for undergraduates. SPS membership, for example, includes membership in two AIP member societies at no additional cost. SPS sponsors sessions on undergraduate research at national conferences and even offers financial support for participants. Connecting students with industry groups, tech blogs, trade shows, and technical sales representatives can lead them to a wealth of information beyond what department faculty are able to provide. The APS "Local Links" program [61] sponsors networking gatherings that can facilitate some of these connections. Providing financial resources to permit students to attend professional meetings and industry shows also puts students in direct contact with potential career opportunities.

11. Encourage and support individual mentoring

The complete preparation of a student for the workforce goes well beyond academic course content and knowledge of common workplace practices. It includes knowledge of how to build a successful and fulfilling career, regardless of the field. This component of training typically occurs one-on-one between a faculty member and a student. It often takes place outside the traditional classroom, in settings such as laboratories, offices, hallways, parking lots, cafeterias, coffee shops, and bookstores. Some faculty members are excellent mentors who naturally relate well to students. To help those who may need coaching in this skill, training in the area of mentoring is available from a variety of sources, including an APS-produced mentor training manual [62].

> **Improve student advising.** At Florida State University, the director of the physics department's Undergraduate Affairs Committee realized that physics students were sometimes receiving substandard advising, so the department took on the direct advising of students. Committee members identified faculty members who would be best suited for giving advice to students in each of the department's four degree tracks, and trained and mentored those faculty on best practices in student advising. The department also upgraded its staff advisor position to require at least a B.S. degree, enabling that individual to more appropriately handle advising concerns while referring more complicated situations to the faculty advisors.

The IT Manager
Shanel Robinson, Information Technologies Manager, Saint Peter's Healthcare System

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Even as a child, when Shanel Robinson had a toy that made noise or had moving parts, she wanted to know how and why it worked.

Robinson's future scientific training would help her develop problem-solving skills to answer the "why" question. She started college at Southern University A&M College in Baton Rouge, Louisiana, as an engineering major, and quickly learned that she could be an electrical engineer with a physics degree. She found her college's physics program refreshing, welcoming, and challenging. The skills and knowledge that she acquired enhanced her analytical, organizational, and leadership skills.

After college, Robinson spent eight years as an avionics guidance and control systems specialist in the U.S. Air Force Reserves. Today she is an Information Technology Infrastructure Library (ITIL)-certified information technologies manager at Saint Peter's Healthcare System in New Brunswick, New Jersey. At Saint Peter's she manages technical staff, leads projects with cross-functional teams, and serves on the system's Leadership Development Team, Diversity Committee, and Space Planning Committee.

Robinson says her physics training has helped her approach problem solving from a scientific perspective, using quantitative methods to come to a resolution. That allows her to be strategic in planning and tactical in execution. The scientific method has also enabled her to successfully work in a collaborative environment even in highly stressful and emotional situations, whether at work or in her community.

6 Recommendations for Successful Programmatic Change

One purpose of this report is to encourage physics faculty to think about change not as a one-time upheaval, but as a continuous process of improvement. While some parts of this process require the engagement of leaders in the institution beyond the physics department, we emphasize that the department is the crucial unit of change [12]. Individuals obviously have critical roles to play, but sustainable change of the type recommended in this report also requires collective action. Faculty, students, and administrators should work together to develop plans that include well-articulated student learning goals, opportunities for students to attain those goals, and processes for measuring how successful students are in attaining them.

Because implementation of any plan requires appropriate personnel, the plan should build on existing strengths and include consideration of hiring decisions over the course of the next five years or so. The plan should also align with and support the future directions of the institution as a whole. Elements of the process are described briefly below and illustrated with examples taken from the case studies that support this report. For departments new to strategic planning exercises or programmatic change principles, additional resources are available that are tailored to academic environments [12,19,63,64].

A. Key steps for developing a strategy

Effective efforts to improve programs share certain characteristics. They address situations as they exist, rather than as they are imagined or hoped to be. They have well-defined objectives. They lay out specific actions to be attempted. They identify those responsible for carrying out actions, and they provide a timeline for the effort. Most importantly, they include plans for assessing the degree to which the objectives have been met, and mechanisms to use the findings to make further improvements.

With these broad general principles as a foundation, effective efforts to implement the recommendations included in this report will generally include the following steps:

(1) Get to know your students and the job opportunities available to them.
(2) Adopt learning goals that specify the knowledge and skills your students will develop.
(3) Map the learning goals to existing program components and identify gaps.
(4) Develop a plan to fill those gaps and implement it.
(5) Assess the results and use the assessment to inform further program modifications.

1. Get to know your students and the job opportunities available to them

Physics faculty must understand the needs, interests, and motivations of current and prospective students, and the career options open to them. While some aspects of the career landscape for physics graduates are very general, and are summarized in other sections of this report, many will be specific to each department, institution, and region. Partnering with other stakeholders (e.g., local employers and other units on campus) may help paint a realistic picture. Suggestions for getting to know students' interests and aspirations include:

- Ask students about their career interests early, during their first year of study.
- Track how students' career interests and aspirations change as they move through the curriculum and participate in projects and research experiences.
- Use exit interviews to find out to what extent the department's program has helped graduates become aware of and interested in pursuing diverse careers.
- Monitor where students go immediately after graduation and several years later.
- Survey alumni/ae to understand their perspectives on what parts of the program worked well and had high value, and what parts did not work as well or had little value.

Keep your finger on the pulse of the department. At St. Mary's College of Maryland, the physics department tracks enrollment and admission data for undergraduate majors and minors, and also tracks awards and other external recognition of students. These data provide a continuously evolving portrait of the department that guides program design, and also provides information that can be sent to the media and the university's central administration. These data have helped the department justify requests to administrators, such as the hiring of an additional faculty member.

Use advising to connect with students. At UW-La Crosse, the physics department chair advises the vast majority of the 160 physics majors every semester in required 20-minute sessions (a registration hold is placed pending this appointment). This process ensures that the chair is deeply connected with students' needs and experiences.

Give an exit survey. At St. Mary's College of Maryland, an exit survey is given to all majors and minors upon graduation. The survey asks graduates about their experiences in the department and their future career plans and goals. The results help the department improve student satisfaction with the courses and the major, and understand students' career aspirations.

Get to know your *future* students. To better understand the pool of prospective students, physics faculty at Carthage College attended local science fairs and met with high school students. This taught them about the newer generation of students, and about the interests of the local student population, both of which are important for this small college, which draws many of its students from the surrounding region.

2. Adopt learning goals

Chapter 4 contains a list of student learning goals developed by J-TUPP in the preparation of this report. This list is intended as a starting point. Some departments may have additional student learning goals tailored to their own programs. In particular, the findings from examining students' own aspirations and interests will inform the choices, as will current and emerging career trends at the local, regional, and national levels.

3. Map learning goals to existing program components to identify gaps

Once learning goals have been defined, a department can evaluate how well the current curriculum and co-curricular activities are working to support student learning. The following questions can help guide this analysis:

- What opportunities exist for students to work toward the goals?
- What opportunities do students have to demonstrate their achievement of those goals?
- Are there important learning goals that are not supported by program components?
- Are there program components that are not supporting important learning goals?
- Which problems are most urgent?
- Which problems can most readily be addressed?

Such an analysis can lead to the development of a *program map* that shows the connections between student learning goals and where they are addressed. Identifying how individual learning goals map onto these opportunities in courses, laboratories, seminar series, research experiences, internships, etc., can ensure that content and skills are introduced in a sequenced, coherent fashion. The map may also allow gaps to be identified and reveal opportunities for improvement.

A program map can also inform a discussion about making the physics major more flexible. By identifying what learning objectives have priority for majors headed to graduate school and what the priorities are for non-academic career pathways, faculty can establish different curricular pathways to provide students opportunities to meet their most important objectives.

Use learning goals to keep your curriculum coherent. The UW-La Crosse physics department's Assessment Committee keeps an eye on program-level learning goals, and determines which courses provide the best assessments of those goals. Over time, committee members found that, while communication skills were listed as a program-level goal, they weren't actually able to assess achievement of this goal because students weren't given opportunities to practice these skills. Faculty began to require each student to give a 10-minute talk in an upper-level course, on a topic of the student's choice, and assessed the presentation using a rubric. Later, in the senior-level capstone course, students give another talk, which is assessed at a higher level than the first. "Without the program goal, we may not have thought about implementing this structure," said professor Eric Gansen.

Write, and rewrite, your learning goals. The first time that Carthage College's physics department wrote student learning outcomes, they were too vague. This first attempt may have been a necessary step, however, and the chair feels that the department is now in a good position to have a more productive conversation about assessment. "Assessment planning was more useful than we expected it to be," said chair Julie Dahlstrom.

4. Develop a plan and implement it

The next step is to identify the specific actions needed to implement the plan, the timeline for implementation, and the team or individuals responsible for specific components.

Anticipating challenges can greatly increase the odds of success for any plan. Changing curriculum has consequences for students and faculty members, and presents logistical concerns. Even if it is clear that significant changes would benefit students, the upheaval necessary to put these modifications into play can be frustrating at times for students, faculty, and staff. Developing a long-term plan that acknowledges such challenges is critical, as is obtaining faculty buy-in. Picking obvious choices that will yield short-term benefits is a good way to start. Limiting the number of alterations undertaken simultaneously allows faculty members and students to see how these changes fit into the broader curriculum design. Choosing appropriate first steps is critical for building confidence in the process.

Identifying and cultivating partnerships may be critical for the success of your plan. For example, developing internships or incorporating industry-standard software into existing courses may require partnerships with other units on campus, or with representatives from local employers including industry, school districts, hospitals, etc. These partnerships can supply needed expertise as well as opportunities for students. Dedicated organizational units such as teaching/learning centers and career centers can advise and assist faculty with program improvements, techniques, and structures. These units can provide interdepartmental opportunities, such as colloquia, reading groups, and seminars, for faculty to learn about and discuss strategies for enhancing programs across departments.

Obtaining resources may also be essential. Although many recommendations in this report can be implemented with resources already available to a department, others may require investment on the part of the institution. Before seeking support, it may be useful to examine how the proposed plans fit into the larger institutional context. The following questions can guide this process:

- *Structural:* What changes to courses, major requirements, co-curricular activities, and mentoring structures are required for success?
- *Human resources:* What staffing is needed, at what level, and involved in what activities? What faculty development or training is needed?
- *Political:* What is the history of such initiatives on your campus? Who will you be competing with for resources? Who are your allies? Who stands to lose if the initiative goes forward? How can you mitigate resistance and leverage support?
- *Symbolic:* How does your initiative celebrate the identity and purpose of your institution? What public relations angles can you tap into?

Give the administration value for their money. At St. Mary's College of Maryland, the physics department chair said, "I try not to ask the administration for something unless I'm giving them something of concrete value in return." For example, when the administration invested money to help establish a research program partnership, the chair ensured that progress from that effort was visible, through continual updates to the administration about media exposure and number of students impacted. The department keeps careful track of data such as student achievement during the program and career paths of alumni/ae, and uses those data to justify continued institutional investment.

5. Assess results and use them to inform further modifications

Nearly all physics departments conduct periodic program reviews to satisfy requirements of their institutions and/or accrediting bodies. One of the goals of this report is to convince departments that some elements of this process can also be useful on an ongoing basis. In particular, this report recommends adopting a closed-loop process involving assessment of the degree to which actions taken have resulted in achievement of goals, and a mechanism to feed that information back to further refine the program. A phased introduction of program changes can facilitate assessment. For example, if a pilot project is planned, faculty members can identify what they hope to learn, to both benefit future iterations and demonstrate the project's effectiveness to others.

To ensure that data on program effectiveness are adequate to inform ongoing changes, it is useful to think in terms of both indirect evidence obtained from alumni through surveys, interviews, etc., and direct evidence based on the performance of current students. It is also useful to think in terms of both program-level outcomes such as professional workplace skills, which may be addressed at several points during the major, and finer-grained outcomes such as knowledge of specific physics content that is covered in a single course or course sequence. The assessment plan should specify which data should be obtained (e.g., portfolios, multiple-choice tests, graded presentations, statistics on student participation in research), how data will be analyzed, and what actions will be taken if results fall short of expectations.

Embrace assessment. The physics department at Carthage College was required to develop an assessment plan that included identification of student learning outcomes and assessments to evaluate those outcomes. Rather than simply going through the motions, the department passionately debated the assessment plan, which resulted in tangible program improvements. "Assessment helps you do your job better," said chair Julie Dahlstrom. "If you don't assess yourselves, someone else will, and you won't be as happy with the results."

Create an assessment committee. At UW-La Crosse, the physics department chair instituted an Assessment Committee, which is responsible for identifying which courses will be used to assess student achievement of program-level learning goals. Over time the committee learned that it was best to assign goals to specific courses; when individual faculty chose which goals they would assess in their courses, nearly all assessed student content learning. By assigning them specific goals to assess instead, the committee can ensure evaluation of the entire range of program goals. Faculty still have freedom to decide how they might assess assigned goals in their courses, though they are required to use some quantitative measure, as well as some form of student feedback. Department faculty now use a variety of assessments, including national, validated concept inventories such as the Force Concept Inventory (FCI), and locally developed rubrics. The Assessment Committee uses these results to write a report that includes longitudinal data, so that faculty can look for trends across courses and over time. An annual faculty meeting is scheduled far in advance—to ensure full attendance—at which these results are made public and discussed by the faculty as a whole. This ensures that the data actually have an impact on the department, and don't simply go into a binder on a shelf.

~10% Percentage of physics bachelor's graduates who become high school physics teachers

Use assessments that will truly measure your innovation. Student course evaluations sometimes suffer when a faculty member first tries an educational innovation. At St. Mary's College of Maryland, the physics department provides balance by using alternative assessments of student learning such as the FCI, allowing them to make a case for a faculty member's teaching excellence even in the face of lowered student evaluations.

Gather data about long-term effects. At Florida State University, when the undergraduate committee recommended creating a new course (Physics Problem Solving) to better prepare undergraduates for the complexity of upper-division coursework, committee members felt that the rationale for the course was obvious and well-founded. However, when the committee recommended that the course be required for the major, and a prerequisite for upper-division work, they knew that it would be best to provide evidence of the course's success. By gathering data that showed a clear correlation between success in Physics Problem Solving and later courses, the committee was able to win faculty support for establishing the course as a requirement.

B. Strategies to support continuous improvement

As mentioned earlier, one-time change is unlikely to lead to sustained improvements. The approach recommended here therefore involves iterative changes in a closed loop. To support continuous improvement, academic leaders should create a culture in which educational innovation is encouraged, sustained when it succeeds, and tolerated when it fails.

Never stop improving. "Don't expect miraculous results in a year or two," cautioned former Carthage College Physics and Astronomy department chair Kevin Crosby (now dean of the Division of Natural and Social Sciences). "Almost everything we tried didn't work out the first time." But because the department was committed to its vision and took assessment results seriously, it was able to make improvements to the program and curriculum over time.

Iteratively improve your curriculum until it works. UW-La Crosse's 3-2 dual-degree program has continually evolved over 10 years, based on data gathered from alumni/ae surveys. Initially, graduates indicated that they needed an engineering-focused thermodynamics course. After changing the course accordingly, the physics department faculty heard from physics majors that the course hadn't prepared them adequately upon graduation. The department now offers engineering-focused and physics-focused versions of the course. It also offers both engineering-focused and physics-focused classical mechanics courses.

Changes discussed in this report may require a shift in a department's reward system to support and recognize faculty who devote time and energy to enhancing graduates' career preparedness. Major program improvements require creativity and sustained, systematic effort, and should be considered a part of a faculty member's record of achievement, alongside traditional teaching, research, and service. Incentive funding can assist faculty who wish to implement improvements. Coupling such funding with assistance in seeking external funding and outreach to other colleagues can optimize its impact. Institutions can also support the establishment of faculty lines and/or interdisciplinary units to help bring in people with expertise relevant to students pursuing diverse career pathways.

82% **Percentage of physics bachelor's graduates working in private-sector STEM positions who are satisfied with their job security**

Reward innovation in teaching. Faculty typically aren't rewarded for teaching innovations. However, as part of the annual review process at St. Mary's College of Maryland, physics department faculty are asked to identify new teaching approaches they have tried, and the chair emphasizes learning new ideas during mentoring sessions. Moreover, faculty are encouraged to attend teaching conferences (most have attended the AAPT-APS-American Astronomical Society-sponsored Workshop for New Faculty in Physics and Astronomy [65]), with course support offered while they are away. Faculty often read educational journals and share what they have learned, and observe one another's classes.

The Software Developer
Michael McNeary, Scientific Software Consultant, McNeary & Associates

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Michael McNeary worked evenings and weekends as a draftsman during high school and went on to earn an associate's degree at El Camino College Compton Center, during which he passed all of the school's math and physics courses. This enabled him to participate in a pre-engineering program run by the Lockheed Corporation in Burbank, California. He then served as a mechanic in the U.S. Air Force and prepared electrical wire harness assemblies for the airplane manufacturer McDonnell Douglas. This experience reminded McNeary how much he had enjoyed physics, so he went back to school for a bachelor's degree in physics from California State University, Dominguez Hills and a master's from California State University, Long Beach.

McNeary enjoyed the hands-on nature of experimental physics, and gravitated toward computer programming. He's since written hundreds of scientific software applications, including a digital filter for sound attenuation and absorption measurements in anechoic chambers (which completely absorb sounds) and reverberation chambers (which create diffuse sound fields).

Switching to semiconductors, McNeary designed software for a number of applications, including pattern-recognition algorithms to ensure quality control in microelectrical mechanical systems. He then wrote several automatic test equipment applications for advanced avionic flight equipment. He now writes software to analyze rocks and other samples in geophysics and petrophysics experiments.

Almost all the software McNeary has written, regardless of the field or the application, embodies fundamental physics principles, he says.

7 What Should Professional Societies and Funding Agencies Do?

The shift in paradigm described in this report—from preparing physics students solely for graduate study to preparing them for the full spectrum of careers they will undertake—will require that all participants in physics education and research adjust their thinking about and approach to undergraduate physics education. Professional societies can use their connections with a wide range of physicists to promote preparation for diverse careers, offer career and professional development resources for students and faculty, and argue for appropriate changes in programs at the agencies and organizations, such as NSF, that traditionally fund research and education in physics.

A. Recommendations for professional societies

Recommendations for actions to be taken by professional organizations to help make career preparation an important component of undergraduate (and graduate) physics programs include:

1. Recognize physicists and physics departments

Professional societies can support the work that physics departments and physicists within and outside of academia are doing to prepare students for diverse careers by acknowledging their efforts publicly in a variety of ways.

Physicists and departments can be invited to write articles and notes in various publications such as *Physics Today*, as well as the newsletters and magazines of physics professional societies (e.g., the *APS Forum on Education Newsletter*). A recent example is a 2013 *Physics Today* article titled "Things your adviser never told you: Entrepreneurship's role in physics education," by Carthage College professor Doug Arion [66]. This article highlights recent efforts by physics departments to build entrepreneurship programs, and includes several case studies. In addition, the article gives a few physics departments national exposure for unique programs that enable students to build skills needed to go directly into the workforce as entrepreneurs. Social media outlets can also be used to promote good ideas and to highlight various departmental programs and faculty members who have been successful in preparing students for diverse careers. Social media are also excellent forums for community building and sharing ideas and best practices.

84% Percentage of physics bachelor's graduates working as high school physics teachers who are satisfied with the level of responsibility of their jobs

Providing prizes and awards to faculty members, physics departments, and non-academic physicists is a very visible way to acknowledge the work to improve opportunities for undergraduates. Existing APS awards recognize faculty members for excellence in instruction in advanced laboratories (the Jonathan F. Reichert and Barbara Wolff-Reichert Award for Excellence in Advanced Laboratory Instruction [67]) and for best practices in education at the undergraduate level (the Award for Improving Undergraduate Physics Education [68]). AAPT offers recognition with the David Halliday and Robert Resnick Award for Excellence in Undergraduate Physics Teaching [69]. However, none of these prizes and awards are given specifically for work to broaden undergraduates' skills to prepare them for a variety of careers. We propose that physics professional societies consider offering the following types of awards, or other modes of recognition such as "physicist of the month," similar to the "AAPT Member Spotlight" [70]:

- Awards to individual faculty members or other physicists who have been champions and prime movers in building programs and partnerships that prepare physics majors for diverse careers.
- Awards to physics departments and programs that are exemplary in preparing undergraduates who are successful in a variety of careers.

2. Offer career readiness professional development activities for students

Professional societies can provide mechanisms for offering workshops, training, and professional development activities for students as well as for recent graduates who have entered the workforce. A large library of appropriate material, including the AIP/SPS Careers Toolbox for Undergraduate Physics Students [56], is available, but resources constraints have so far limited the dissemination of these materials to promote wide use by the physics community. Additional funding could enable more workshops and panels based on these materials to be offered at national and regional meetings.

$37,000 Median starting salary of a high school physics teacher

3. Offer workshops to assist current faculty in providing career preparation activities

Most physics faculty members do not have the industrial experience or connections to carry out all of this report's recommendations. Professional societies can train and educate faculty in the knowledge, skills, and attitudes they need to more effectively prepare their students for diverse careers. Existing materials such as the AIP/SPS Careers Toolbox for Undergraduate Physics Students [56] and the

APS Mentoring Seminars [62] can serve as the basis for workshops to assist faculty members in infusing career preparation into their programs. These materials can also be shared with campus career centers. Additionally, student-oriented workshops could be offered at national, regional, and divisional meetings. Professional societies can also help by convening conferences or workshops for department chairs to share, disseminate, and develop innovative programs that promote professional preparation and career readiness.

4. Provide forums for the interchange of ideas about physics and physics careers that are "applied" and "industrial"

Conferences and refereed journals are major conduits for the publication and dissemination of research from the physics community. However, there are few opportunities within the professional societies for individuals trained in physics, but following a variety of career paths, to exchange ideas with peers and with students. Forums that allow physics professionals working outside academia to communicate about the reality of the work environment, current real-world applications of physics concepts, necessary training, and appropriate expectations would be of value not only to students but also to academic physicists who prepare students for such careers.

Professional societies can also provide forums at their meetings for presentations about multidisciplinary programs and programs that provide support for broad career options, as has been done at AAPT meetings. Presentations on careers in the semiconductor industry, careers in science policy, and nontraditional career choices have also been featured at APS meetings in the recent past [71], in partnership with the AIP Corporate Associates. Continuation and expansion of these offerings can increase awareness within the physics community of the broad range of career choices open to physicists, and how students can best prepare to pursue them. Offering a platform for the presentation of research in applied areas such as numerical modeling, finance, industrial process management, and quality control, is also a valuable service that professional societies can provide. If students see careers in areas outside of standard physics research publicized and highly valued, they will be more likely to consider such careers.

84% **Percentage of physics bachelor's graduates working in government or national labs who are satisfied with their salary and benefits**

5. Ask physics student organizations to advocate for their departments to adopt the recommendations of this report and develop student-based programs that implement them

The Society of Physics Students (local chapters and the SPS National Office) and other student organizations (e.g., APS Women in Physics groups) are in a unique position to engage undergraduate students, so bringing them into the conversation about programmatic change can assist departments in developing strategies and adopting best practices. This can also provide a way to connect departments to one another through national professional organizations.

6. Encourage society members outside academia to participate in career readiness activities

Society members from diverse non-academic work environments should be encouraged to provide research-based internship opportunities to undergraduate physics majors, and to engage with their academic colleagues in collaborative research involving students. In this way, such members can participate in preparing future members of the physics workforce.

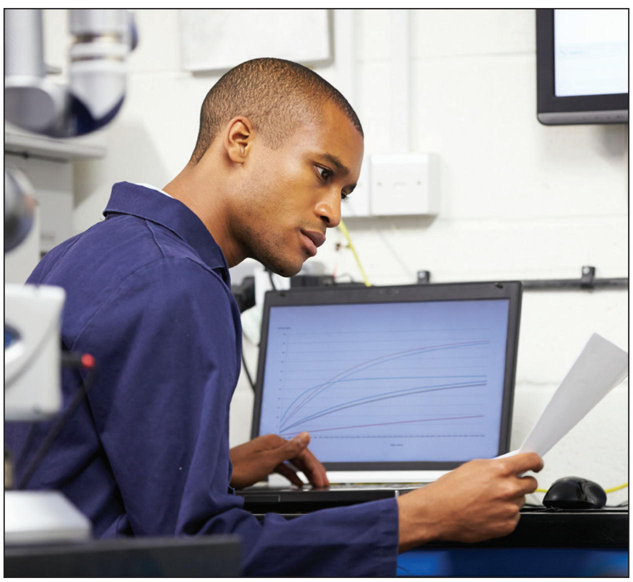
7. Promote education in career readiness through society activities

Physics professional societies should be aware of issues described in this report, and should address them in future statements, policies, reports, and projects, possibly through their participation in the Physical Sciences Education Policy Coalition (PSEPC). PSEPC seeks changes in federal policy that impact physical sciences education. There will doubtless be many other ways for professional societies to incorporate practices and strategies outlined in this report.

B. Recommendations for funders

1. Fund industrial and applied research projects within the academic environment and through joint academic/industrial partnerships

There are many opportunities for undergraduate physics students to do research projects that may not advance our understanding of fundamental physics, but that are applied or developmental. Most national organizations that fund physics research support "pure" research projects, but they should also be amenable to supporting projects that have broader impact. Such projects provide opportunities for students to gain valuable technical and workplace skills as they apply physics content to new and interesting venues—especially those that are cross- and inter-disciplinary and have the potential to be commercialized.



This change will require that funders create proposal review panels that include individuals with industrial or commercial experience as well as academic physicists. This will ensure such panels encompass a much broader viewpoint and understanding of the commercial environment and the skills needed to be successful there than is needed for basic research proposal reviews. It may also be necessary for agencies to augment their criteria for successful grant outcomes to include patents, internship opportunities, and other measures beyond published papers and presentations at scientific conferences.

While the Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) funding pathway exists at NSF, additional sources of funding for projects that are grounded in physics research and have potential for commercial value are needed. SBIR/STTR projects are generally relatively close to commercialization. Funds for earlier-stage research are needed, as are new funding paradigms that integrate undergraduate research and career development into these types of projects.

2. Fund development of curricular and co-curricular ways to engage physics students in career preparation

As discussed in this report, the current standard physics curriculum does not explicitly teach the knowledge and skills needed for diverse careers. Funding agencies should provide resources for physics faculty to develop, test, and disseminate curricular innovations aimed at fostering innovation, entrepreneurship, and preparation for diverse carriers. Similarly, funds are needed to provide students with research and internship experiences that apply physics to commercial problems and other areas, including high school teaching.

8 Summary

The physics community has been extraordinarily successful in the past three-quarters of a century at producing talented individuals who have advanced our understanding of the physical world, created technology that has improved the lives of people everywhere, and addressed pressing societal problems. This success has come despite the fact that most physics programs are explicitly designed to prepare their graduates to do only the first of these.

The overwhelming majority of people who receive a bachelor's degree in physics are employed outside academia for all or part of their careers, and are engaged in a wide variety of work. Tasks such as working in teams, technical writing, using computer programming to solve problems, applying physics to solve interdisciplinary problems, designing and developing products, managing complex projects, and working with clients are central to graduates' everyday work. Yet the explicit and purposeful development of the skills necessary to succeed at these tasks forms a small part of most physics programs, if it is addressed at all.

Physics departments that aspire to serve all of their students well will foster the knowledge and skills their students need to be successful in a wide range of careers, including, but not limited to, graduate education in physics and related fields. To better prepare students in this way does not require that a department abandon the rigorous technical education that physicists take pride in. It does, however, require that physics faculty members become informed about the skills and knowledge valued by potential employers of their graduates, and that departments make appropriate modifications to curricular and co-curricular aspects of their programs. Departments that take up this challenge and provide the preparation that their graduates need will not only better serve all of their current students, but are also likely to attract a more diverse set of students, with a broader range of career interests.

93% Percentage of physics bachelor's graduates working in the active military who are satisfied with their opportunity for advancement

The Joint Task Force on Undergraduate Preparation in Physics was charged with the following question: *What skills and knowledge should the next generation of undergraduate physics degree holders possess to be well prepared for a diverse set of careers?* An overwhelming consensus, backed by our own investigations as well as a wide variety of reports by other organizations, indicates that the current physics curriculum is not providing many of the key knowledge, skills, and attitudes students need to succeed in 21st-century careers. In this report we outline a roadmap that departments can use to assess the employment landscape their graduates are entering; understand the knowledge, skills, and attitudes that physics graduates need for successful careers; develop learning goals that will promote their graduates' success; and ensure that those learning goals are met.

Increasing the extent to which a physics degree prepares its graduates for future employment will bolster the health and vitality of undergraduate programs. Reframing a physics program to better prepare students for a broad range of careers can also enhance the success of students who choose to pursue graduate education in physics. Connecting the research done in the academic setting with topics of interest to the private sector and government will not only help students who participate in that research gain the knowledge and skills needed in their careers, but can also help faculty members establish new collaborations and contacts outside academia that can lead to new questions to address and new sources of research funding.

To carry out successful programmatic change to enhance the preparation of graduates for diverse careers, a physics department, with faculty, students, and administrators working together, should develop a plan that includes well-articulated student learning goals tailored to the career aspirations of the students, opportunities for students to attain those goals, and a process for measuring how successful students are in attaining them. The relevant learning goals include physics-specific knowledge, scientific and technical skills, communication skills, and professional and workplace skills. Physics programs already incorporate elements intended to allow students to acquire at least some of the necessary knowledge, skills, and attitudes, whether or not this was done in the context of explicitly articulated learning goals. However, a program is much more likely to be successful in meeting the needs of its students if faculty members are specific about learning goals and the means to achieve and assess them. Most of the learning goals a department chooses to adopt can be achieved by infusing current course offerings with new skills or by taking advantage of co-curricular activities, and most goals can be pursued through a number of different channels.

The paradigm shift from preparing physics students solely for graduate study to preparing them for the full spectrum of careers they will undertake requires that all participants in physics education and research adjust their thinking about and approach to undergraduate physics education. To support diverse career initiatives, professional societies can use their connections with a wide range of physicists to promote preparation for diverse careers and to argue for appropriate changes in programs at agencies and organizations, such as NSF, that traditionally fund physics research and education. Actions such as recognizing physicists and physics departments that contribute to the preparation of students for diverse careers, engaging SPS in associated activities, offering professional development workshops for students and faculty members, and providing forums for dissemination of research and information about careers in applied areas, are all part of the work of societies such as APS, AAPT, and AIP, as well as other groups such as the National Society for Black Physicists and the National Society for Hispanic Physicists.

A physics department that acts on the recommendations contained in this report will reap many rewards. Investigating the employment outcomes of the program's recent graduates and the career aspirations and prospects of its current and future students, as well as the broader physics career landscape, will allow faculty members to better know their students and help those students achieve their full potential after graduation. Adopting overall learning goals will help a department develop a coherent view of its program as more than the sum of individual courses. Bringing together faculty, administrators, students, and alumni/ae to craft a strategic plan to accomplish specific learning goals will foster departmental cohesion and a sense of ownership of the program shared by all concerned.

Most importantly, implementing the plan will increase the career success of the program's graduates, which should be a goal for any physics department. Doing so will enhance the reputation of the department and attract a talented and diverse group of students who might otherwise have chosen different disciplines or institutions that appeared to offer better employment prospects or greater opportunities to serve society. Enhancing students' engagement with applied research will result in access to new resources and new, interesting research questions. Assessing the results of the changes to the program, and using the assessment in a cycle of continuous improvement, will foster similar practices in regard to other aspirations the department may have, making it more effective at accomplishing any kind of desired change.

Ultimately, physicists and physics departments will choose to follow the recommendations of this report because they desire two things. They desire to prepare 21st-century graduates as effectively as possible for the diverse careers that they can be expected to have—in other words, they desire to do right by all of their students. They also desire to obtain the many benefits to the department that will follow from fulfilling the first desire—in other words, they wish to pursue enlightened self-interest. If enough physicists make this choice, we are confident that our discipline will continue in robust health through this century and beyond.

The Teacher
Kate Miller, Physics Teacher, Washington-Lee High School

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Kate Miller fell in love with physics in high school, when she realized that the equations she was learning could explain what she did in her favorite activity: gymnastics. She received her bachelor's degree in physics from the University of Michigan, and her master's degree in education from the University of Pennsylvania. There, she learned how to recognize and address student misconceptions and how to present material in multiple ways to help students with different learning styles.

Miller is now a physics teacher at Washington-Lee High School in Arlington, Virginia, an urban/suburban school just a few miles from the nation's capital, with a diverse student population and several other physics teachers with whom she can collaborate. Miller teaches both introductory physics and an advanced program called international baccalaureate physics, in which students learn about topics like climate change, thermodynamics, and astrophysics.

Students in Miller's classes design, build, and market model roller coasters; experience Newton's laws by playing tug-of-war; and pursue year-long independent research projects. Miller's students are fortunate in another way: Only around a third of the nation's new high school physics teachers have a degree in physics or physics education.

Teaching is no less intellectually demanding than a career in research or industry, Miller says. "It's just as rigorous, challenging, and tiring as any other options a physicist has in front of them."

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Glossary

3-2 program A cooperative program between two institutions (typically a liberal arts college and a university with an engineering school) in which a student matriculates at the liberal arts institution, pursues a physics degree, and transfers to the engineering school after the junior year. At the end of the fifth year the student receives two bachelor's degrees, one in physics and the other in engineering.

ABET Accreditation Board for Engineering and Technology, a not-for-profit, nongovernmental accrediting agency for programs in applied science, computing, engineering, and engineering technology recognized as an accreditor by the Council for Higher Education Accreditation.

Capstone experience An academic experience in the final year in which students are expected to integrate the various aspects of their physics study and extend and apply the knowledge they have gained.

Co-curricular Activities and learning experiences that complement what students learn in the formal courses that constitute the curriculum.

Co-op A cooperative education program conducted in partnership with an employer that provides academic credit for a structured job experience meant to give students practical work experience that complements their coursework.

Cultural and social competence Knowledge, skills, behaviors, and attitudes that enable individuals to function effectively in a variety of cultural and social environments.

Entrepreneurship The capacity and willingness to develop, organize, and manage a new venture and assume any of its risks in order to make it succeed.

Internship A temporary position with an employer with an emphasis on on-the-job training rather than simple employment. Internships can be paid or unpaid.

Learning Assistants or LA program A program, often modeled on the one developed at the University of Colorado Boulder, in which undergraduate students assist with instruction in large-enrollment courses, often facilitating small-group interaction. Learning Assistants are intended to enhance student learning in large-enrollment courses by making them more collaborative, student-centered, and interactive.

Learning goals Brief statements of what students are expected to be able to do at the end of a lesson, course, or program as a result of the instruction.

LinkedIn A business-oriented social networking website for professionals that allows users to make connections with people they have worked with, post their work experience and skills, look for jobs, and look for workers.

Quality assurance Administrative and technical activities to assure that requirements and goals for a product, service or activity will be fulfilled by preventing mistakes or defects in manufactured products and avoiding problems when delivering solutions or services to customer. It involves systematic measurement, comparison with a standard, monitoring of processes, and an associated feedback loop that confers error prevention.

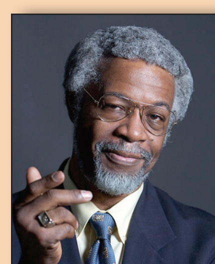
SPIN-UP report Strategic Programs for Innovations in Undergraduate Physics, a report produced in 2003 by the National Task Force on Undergraduate Physics (NTFUP) jointly organized by the American Physical Society, the American Association of Physics Teachers, and the American Institute of Physics. The project (also supported by the Exxon-Mobil Foundation) sought to identify characteristics of undergraduate physics programs that were "thriving," meaning that they were increasing the number of bachelor's degrees they awarded (or maintaining a number much higher than the national average for their type of institution) during the 1990s, when the number of bachelor's degrees in physics was declining nationally.

Project Committee

Douglas Arion is Donald Hedberg Distinguished Professor of Entrepreneurial Studies and Professor of Physics and Astronomy at Carthage College, President of Galileoscope LLC, and a founder and Senior Project Advisor of the Center for Advanced Technology and Innovation, following a career as Assistant Vice President and head of the Applied Physics and Engineering Division of Science Applications International Corporation. He received his AB from Dartmouth College and MS and PhD from the University of Maryland, College Park. Dr. Arion is a Fellow of the American Physical Society, has received the Distinguished Service Award from Sigma Pi Sigma, created *ScienceWorks*, the first undergraduate technology entrepreneurship program, and organizes and delivers entrepreneurship and innovation workshops, the Industrial Physics Forums cosponsored by the American Institute of Physics (AIP) and the Abdus Salam International Centre for Theoretical Physics (ICTP). As an individual with both industrial and academic experience, as creator of *ScienceWorks*, as a contributor to economic development efforts in several locations across the country, and as a research physicist, he brings to J-TUPP both an understanding of what students need to know and be able to do, and experience in achieving those goals with undergraduates.

Walter Buell is Principal Director of the Electronics and Photonics Laboratory at The Aerospace Corporation, where he leads a group of about 100 scientists and engineers supporting the national security space enterprise in the areas of energy, microelectronics, and photonics technology. He earned his bachelor's degree in physics from the University of Rochester and master's and PhD in physics from the University of Texas at Austin; he was a visiting researcher at the Max Planck Institute for Quantum Optics and performed postdoctoral research at the State University of New York at Stony Brook. Dr. Buell is a lifetime member of the American Physical Society (APS) and The Optical Society (OSA), serves on the APS Industrial Physics Advisory Board, and was recently Vice-Chair of the National Research Council Committee on Review of Advancements in Active Electro-Optical Systems to Avoid Technological Surprise Adverse to U.S. National Security. As a practicing industrial physicist in the aerospace industry, he brings experience in both basic and applied research in the non-academic sector, as well as experience mentoring students and practitioners across the academic-industry environments.

Beth A. Cunningham (AAPT liaison) is Executive Officer for the American Association of Physics Teachers (AAPT) after a long tenure in higher education. Following a postdoctoral fellowship at the University of Minnesota, Dr. Cunningham taught for one year in the physics department at Gettysburg College before joining the physics department at Bucknell University in 1989 and becoming Associate Dean of the faculty in the College of Arts and Sciences in 2000. In 2006, she was appointed as Provost, Dean of the Faculty, and Professor of Physics at Illinois Wesleyan University. At AAPT she provides leadership for the association as well as oversees a number of physics education initiatives at the K-12 and higher education levels, including programs that support women in physics. She earned her bachelor's, master's and doctorate degrees from Kent State University. As an AAPT liaison to J-TUPP, she brings experience on numerous national committees and several Boards of Directors and provides expertise on organizational change and faculty leadership to improve STEM education.



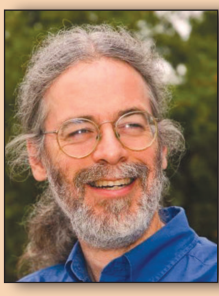
Sylvester James Gates Jr. is currently serving as the University System of Maryland Regents Professor, the Center for String and Particle Theory Director, Distinguished University Professor, John S. Toll Professor of Physics, and Affiliate Professor of Mathematics at the University of Maryland. He received two BS degrees and a PhD degree from the Massachusetts Institute of Technology, and has devoted the last 40 years to education and research. He serves on the U.S. President's Council of Advisors on Science and Technology, National Commission on Forensic Science, and Maryland State Board of Education. President Obama awarded Dr. Gates the National Medal of Science, the highest award given to scientists in the U.S., at a White House ceremony in 2013. As a member of J-TUPP, he brings experience on numerous national committees and task forces as well as on organization and design of national-scale projects to improve physics education.

Sandeep Giri manages the Advanced Technology Manufacturing Engineering Group of Project Loon, within Google [X] in its Silicon Valley facility. He earned his bachelor's in physics and mathematics from Coe College, and his MS in materials science and engineering from Stanford University, and he discontinued his PhD from Stanford University. Giri has developed and brought to market multiple products (smartwatch, e-reader, smart phone, Google glass) spanning many industries (optics, MEMS, displays, flat panel, semiconductor, free-space optical communication, stratospheric balloons), brought up manufacturing facilities in US, Europe, and Asia, holds several US and international patents, and has coauthored multiple technical publications. As a physicist in industry, he brings to J-TUPP a private-sector perspective to enable universities to prepare physics majors for success in various careers.

Renee Michelle Goertzen (APS liaison) is Education Programs Manager for APS. She earned her PhD in physics (physics education) from the University of Maryland, College Park. She works on the Physics Teacher Education Coalition and the APS Conferences for Undergraduate Women in Physics. As an APS liaison to J-TUPP, she brings expertise in physics education research and faculty professional development, along with knowledge of national projects in physics education and diversity.

Paula R.L. Heron (Co-chair) is a Professor of Physics at the University of Washington. She holds a BS and an MS in physics from the University of Ottawa and a PhD in theoretical physics from Western University. She is a Fellow of the APS, cofounder and co-Chair of the biannual conference series "Foundations and Frontiers in Physics Education Research," and Associate Editor of *Physical Review – Physics Education Research.* Dr. Heron brings to J-TUPP extensive experience on national committees and advisory boards, as well as expertise in physics education research.

Robert C. Hilborn (AAPT liaison) is Associate Executive Officer of the American Association of Physics Teachers. He earned a bachelor's degree in physics (with highest honors) from Lehigh University and MA and PhD degrees in physics from Harvard, then served several decades as a physics faculty member at Oberlin, Amherst, and the University of Texas at Dallas. His physics research has focused on atomic and molecular physics tests of fundamental symmetries, nonlinear dynamics and chaos, and computational modeling of gene regulatory networks. He brings to J-TUPP experience leading national STEM education projects, including service as President of AAPT, a member of the Advisory Committee for the Mathematical and Physical Sciences Directorate of the National Science Foundation; Chair of the National Task Force on Undergraduate Physics Programs, which led to the Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) report; a member of the Board of Advisors for the College of Science, Engineering, and Technology of Jackson State University; a member of the American Association of Medical Colleges (AAMC) and Howard Hughes Medical Institute joint Committee on the Scientific Foundations for Future Physicians; and the AAMC MR5 MCAT review committee.



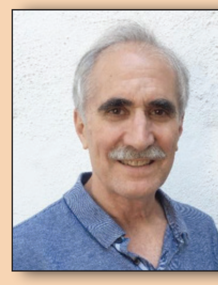
Theodore Hodapp (APS liaison) is Director of Project Development and Senior Advisor to Education and Diversity for APS, following 14 years in academia with forays into the private sector (3M), national labs, and the federal government (NSF Program Officer). He earned his bachelor's and PhD in physics (quantum optics) from the University of Minnesota. Hodapp is a Fellow of APS and the American Association for the Advancement of Science, and provides senior leadership for the APS Bridge Program, the APS Conferences for Undergraduate Women in Physics, the Physics Teacher Education Coalition (PhysTEC), the AAPT/APS/AAS New Faculty Workshop, and the APS National Mentoring Community. As an APS liaison to J-TUPP, he brings experience on numerous national committees and task forces, as well as organization and design of national-scale projects to improve physics education.

Elizabeth McCormack is Professor of Physics at Bryn Mawr College, which she joined after receiving her bachelor's degree in astronomy and physics from Wellesley College, and her PhD in physics from Yale University, and working at Argonne National Laboratory as an Alexander Hollaender Distinguished Postdoctoral Fellow and and as a Physicist. She is a Fellow of the APS and has been Chair of the Faculty, Director of the Center for Science in Society, Director of the STEM Posse Program, Dean of Graduate Studies, and Associate Provost at Bryn Mawr College and is currently Chair of the Board of Directors of the Research Corporation for Science Advancement and a member of the Board of Advisors to Project Kaleidoscope at the American Association of Colleges and Universities. She brings to J-TUPP broad experience in academic research, teaching, and administration and a deep commitment to improving physics education through student-centered and inclusive teaching and learning.

Laurie McNeil (Co-chair) is Bernard Gray Distinguished Professor and former Department Chair in the Physics and Astronomy Department at the University of North Carolina at Chapel Hill. She earned a bachelor's degree (chemistry and physics) from Radcliffe College of Harvard University and a PhD in physics (experimental condensed matter) from the University of Illinois at Urbana-Champaign, then did postdoctoral work at MIT. She is a Fellow of APS, was the inaugural holder of both the Kathryn A. McCarthy Lectureship at Tufts University and the Dorothy Daspit Lectureship at Tulane University, and serves as a Deputy Editor for *Journal of Applied Physics*. She brings leadership experience in curricular and pedagogical reform in her own department and on her own campus, as well as from the National Task Force on Undergraduate Physics, which produced the SPIN-UP report in 2003.

Helen Quinn is Professor Emerita of Particle Physics and Astrophysics at the SLAC National Accelerator Laboratory. She earned a PhD in physics from Stanford University and has taught physics at both Harvard and Stanford. Her research and her contributions to science education were recognized by the 2016 Compton Medal of APS, and she holds numerous other awards for her research. Dr. Quinn is a Fellow and former President of APS and a member of the National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society. She brings to J-TUPP a broad view and knowledge of science education at all levels, from preschool to PhD.

Quinton L. Williams is Professor of Physics and Chair of the Department of Physics and Astronomy at Howard University, following several years of experience gained in industry (Lucent Technologies – Bell Labs) and a venture-capital-funded start-up company in photonics. He earned his doctorate in physics from the Georgia Institute of Technology in Atlanta. Dr. Williams has served as President of the National Society of Black Physicists, a member of the Governing Board of the American Institute of Physics, and a university administrator in the role of Provost. Having worked on increasing diversity in physics for nearly 25 years, Williams brings his broad experience gained through work in private industry, academia, and service on numerous national committees and boards.



Lawrence Woolf is Sciences Manager of Materials Science in the Mission Systems group of General Atomics Aeronautical Systems, and President and Chairman of the Board of the General Atomics Sciences Education Foundation. He earned his bachelor's in physics from Rutgers College and his PhD in physics (condensed matter) from the University of California, San Diego, then completed a postdoc at the Exxon Corporate Research Science Laboratory. Dr. Woolf is a Fellow of the APS, holds 24 patents, has been a member of 25 NSF review panels, chaired the APS Forum on Education, and participated in the design and review of multiple national K-12 science curricula. As President of the General Atomics Sciences Education Foundation, he created the GASSSS (GA Scientists Supporting Science for Students) program, which has catalyzed the involvement of hundreds of General Atomics' employees in education outreach. As an industrial member of J-TUPP, he brings 36 years of industrial experience as a physicist, materials/optical scientist, lead scientist, engineering manager, and program manager; extensive writings and presentations on preparing students for nonacademic careers; and leadership in many national science education efforts, ranging from elementary to graduate physics education.

Appendix 1: Case Studies

Carthage College Case Study

About Carthage College

- Location: Southeastern Wisconsin (Kenosha)
- Type of institution: Private, liberal arts
- College ranking: 154th among liberal arts institutions (*U.S. News & World Report*)
- Physics faculty: 5 tenure-track, 4.5 full-time equivalent
- Students enrolled: 2,500 (college as a whole); 74 (physics majors declared)
- Physics bachelor's degrees awarded per year: 10
- Physics degrees offered: B.A. with optional concentration in astrophysics, plus a 3-2 dual-degree engineering program. Informal recommendations given for those pursuing graduate studies or secondary teaching.

What can we learn from Carthage College? *Be intentional.*

The word that comes to mind when describing the physics program at Carthage College is "**intentional.**" The department has a clear sense of mission: to encourage diverse students to pursue physics, and to support them in their eventual careers. Every aspect of the major, including student recruiting, creation of student community and space, flow through the course sequence, requirements and coursework, and research opportunities, is consciously and intentionally designed to support this goal.

The departmental perspective is very strongly **centered on the student experience**: what students are interested in, their academic and psychological needs, what they experience in their courses and other activities during their undergraduate careers, and where they will go after graduation. By many measures the department has been successful in meeting its goals: The department recruits, retains, and graduates a large number of majors for its size, including roughly equal numbers of male and female students, and these graduates pursue diverse careers.

The current and former department chairs offer the following advice to other departments:

> "Have a clear sense of your mission."
> "Don't expect miraculous results in a year or two. Believe in your vision, and persist."
> "Don't skimp on assessment."
> "Figure out where your students are at, and what their interests are."
> "Offer a flexible major with multiple entry points."

How did the Carthage College physics department get to where it is today?

Physics faculty members took their first serious look at their program and curriculum during the late 1990s, when many physics departments were forced to close due to low enrollment. Sparked by a sense of urgency as the caretakers of the department and the discipline, both of which were under threat, two Carthage faculty members attended an American Association for Physics Teachers (AAPT)-led national conference (Building Undergraduate Physics Programs for the 21st Century, 2008), where they learned how other departments were revitalizing their programs through innovative course structures and flexible majors.

Based on this experience, Carthage faculty members redesigned their department's introductory curriculum to incorporate active learning in a studio format, and to engage students in active learning and problem solving across the curriculum. The department also instituted a flexible major to allow students to pursue a variety of careers. Over time, these thoughtful efforts have significantly increased the number of graduates in the department, and the department and its students have earned a strong reputation.

However, success didn't happen overnight. "Almost everything we tried didn't work out well the first time," says former department chair Kevin Crosby. "But we were committed to the vision and took the results of assessment seriously, and over the years we saw improvement in our student outcomes."

Three key elements of the Carthage College physics department's approach include the following, described in more detail below:

(1) Visioning and strategic planning
(2) Assessment and continuous improvement
(3) Student success is the top priority

(1) Visioning and strategic planning has been a driving force across the department. Since the late 1990s, department leaders have thought carefully about the vision for the department, stemming from a sense of urgency and a need to be seen as vital to the college and its students. Recognizing that small class size doesn't adequately differentiate its program from those at other small liberal arts institutions, department faculty members considered their program's strengths and student audience, and positioned themselves as providing students diverse career options and practical, real-world experience.

The strategies used by the department stem from this vision. Departmental leadership was not autocratic, and the collegial atmosphere of this small department has resulted in a cohesive faculty vision. Annual department retreats and informal interactions among faculty members are seen as important factors. When the college administration required that all departments engage in formal strategic planning, the physics department embraced that planning and came away with some solid ideas about how to change its program, in contrast to many other departments for which the process was more pro forma. The department's decision to address the needs of students who do not pursue graduate studies in the discipline, and the general contribution of the physics department to recruiting students to the university, have earned the tangible support of the administration.

(2) Assessment and continuous improvement of student and program outcomes has driven programmatic changes. Both the central administration and the department chair have encouraged a culture of continuous improvement, which includes allowing experimentation with program and curriculum, and not penalizing short-term failures. Indeed, the first attempt at an assessment plan to identify and measure student outcomes resulted in rather vague learning goal statements that did not fully encapsulate what the department wanted from its majors. This attempt may nevertheless have been a necessary growing pain for the department, and chair Julie Dahlstrom feels that they are now in a good position to have a more productive conversation about assessment. "Assessment planning was more useful than we expected it to be. You'll be surprised at how often you'll learn something surprising and useful from assessment," says Dahlstrom. "If you don't assess yourselves, someone else will, and you won't be as happy with the results."

(3) Student success is the top priority of the department and drives the program. Many of the strategies described below can be summarized as "looking out for the students." Faculty members in the department feel a heightened responsibility for individual students, and are continuously available to them in many ways: reaching out to individual students in recruiting efforts, advising students on their degrees and careers, teaching professional skills, and helping students find research opportunities and jobs. The department will even add additional sections of introductory courses if needed. The culture and small size of the department, as well as the liberal arts focus of the institution, support this deep engagement on the part of faculty.

Strategies used at Carthage College

These broad values have led to the following concrete strategies:

(1) Students are actively recruited from many venues. Recruiting is very proactive at Carthage, supporting the aim of attracting diverse students. "We treat everything as a recruiting opportunity," explains Crosby. The department chair and physics faculty members meet personally with prospective students and parents, and the department sends a brochure to all students entering the college. The department's outreach programs reach over 1,000 students each year, including many at local high schools that serve as sources of potential students. Non-major courses such as "Good Vibrations" and "Cosmology" are geared to get students to think about physics as a potential major. And because of the multiple entry points for the degree (see below), students are not penalized for making this choice after the fall of their freshman year.

(2) The degree program is very flexible, and explicitly acknowledges multiple career pathways. The formal requirements of the Carthage physics major are similar to those of other departments, but the program offers several concentrations, most of which are not formal tracks (i.e., they will not show up on a transcript, with the exception of the 3-2 engineering program and the astrophysics concentration). Rather, the department provides several catalog options, with a recommended set of courses for different career tracks, such as graduate school and teaching physics at a secondary level. Those pursuing an education minor, for example, are already subject to many requirements and scheduling constraints, and so providing recommended course lists (rather than a formal degree program) explicitly recognizes this career pathway, while allowing students to tailor the program to their needs and constraints. Students feel that they are supported regardless of whether their ultimate career goals include graduate school or not.

(3) Students can enter the degree at multiple points. An unusual feature of Carthage's physics program is that the curriculum is intentionally coordinated to allow students to graduate in four years even if they do not take introductory physics in the first year. Each course in the introductory series is offered every semester at the same time, so that students can enter the major in the fall or the spring, and can easily switch between the courses if they have been mistakenly placed. The introductory sequence is a studio format (with connected lectures and labs), which also simplifies scheduling and creates strong student cohorts. The department has adopted a policy of "excitement first, math second," and explicitly supports students who would like to study physics, even if their math background is not ideal.

(4) **The department explicitly and actively supports student community and cohorts.** The Carthage physics department carefully considers how students are inducted into the major, and helps them feel that they belong in the department. "Consider how you will help students develop an identity as a physics major," says former chair Jean Quashnock. The department gives students control of a comfortable student lounge space, and holds tutoring sessions, Learning Assistant meetings, and Society of Physics Student (SPS) meetings there. The department subsidizes SPS membership for any student who is interested, not just physics majors. The department provides many opportunities for underclassmen and upperclassmen to interact, so that underclassmen can see potential future pathways for themselves in these older students. Additionally, student identification with their graduating class is encouraged both through the introductory studio class and by ensuring that all students enroll in Modern Physics as a cohort.

What is unique about Carthage College?

The Carthage Physics and Astronomy Department is a small department (five faculty, 4.5 FTE), which enables it to be a very cohesive department with common practices and norms, such as the emphases on individual student mentoring and recruiting from diverse pools. Additionally, because Carthage is a liberal arts institution, with less time required for research than at more research-intensive institutions, faculty members are more available to focus on teaching and mentoring students, and engaging in activities such as attending local science fairs. Lastly, while the faculty is small, it has a wide range of expertise (including medical physics, entrepreneurship, and astrophysics), allowing it to offer a range of concentrations and research experiences to students. These factors do not mean that it is impossible for a different type of institution to use the strategies employed at Carthage, but it is important to be aware of local strengths and barriers to change when adapting ideas from other institutions.

For more information

<table>
<tr><td>Contact: Jean Quashnock, jmq@carthage.edu, or Julie Dahlstrom, jdahlstrom1@carthage.edu</td><td>Department website: https://www.carthage.edu/physics/</td></tr>
<tr><td colspan="2">Course catalog: https://www.carthage.edu/academics/catalog/</td></tr>
<tr><td colspan="2">Sources: AIP Career Pathways project documentation; interviews with Jean Quashnock (former chair), Kevin Crosby (former chair, Dean of Natural and Social Sciences), and Julie Dahlstrom (current chair).</td></tr>
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Florida State University Case Study

About Florida State University

- Location: North Florida (Tallahassee)
- Type of institution: Public research university
- College ranking: 96th among national universities (*U.S. News & World Report*)
- Physics faculty: 43 tenure-track, 2–4 full-time instructional staff
- Students enrolled: 41,473 (college as a whole); 160–200 (physics majors declared)
- Physics bachelor's degrees awarded per year: 30
- Physics degrees offered: B.S., M.S., and Ph.D. Bachelor's in physics, physics and astrophysics, physical science, and physical science with FSU-Teach.

What can we learn from Florida State University? *Prepare all students for success.*

As a large research university, the physics department at Florida State University must balance competing priorities, including graduate and undergraduate education and research productivity, among a diverse faculty. A **strong undergraduate committee** and a focus on **preparing all students for success** have led to a number of successful **curricular interventions** that prepare students for several key transitions in the major, including entrance to the major and the transition to the upper division, and support students in developing communication and computation skills within the context of the discipline.

These interventions help keep students from leaving the major and better prepare them for success. The department's other strong focus is on **student community**. Through intentional group work (particularly at the lower level), connection to faculty, and a centrally located lounge that keeps students visible, students are strongly encouraged to interact with one another.

How did the Florida State University physics department get to where it is today?

Three key elements of the department's approach are the following, described in more detail below:

(1) A strong undergraduate affairs committee, supported by the faculty
(2) A focus on the undergraduate experience for all students
(3) Strategic teaching assignments at the introductory level

(1) A strong undergraduate affairs committee, supported by the faculty, has led substantial improvements in the department. As at most large institutions, departmental committees make recommendations that are then discussed and voted on by the broader faculty. The committee, which has been led by professor Susan Blessing for the last eight years, is strong and well-informed: Members attend conferences, bring back ideas, have discussions, and make recommendations to the faculty.

For example, when the committee proposed offering additional courses to improve student success within the major (Communication in Physics, Discovering Physics, and Physics Problem Solving; more detail below), the faculty agreed that these were critical, and eventually approved them as required and/or prerequisite courses, once data demonstrated their effectiveness. However, some of these additional courses are taught as an overload, and it can be difficult to ensure consistent implementation of a novel structure across the faculty.

(2) A focus on the undergraduate experience for all students is exemplified in many of the nonstandard courses offered by the department, which aim to prepare all students for success. "We're trying to get beyond the top 3% [of students] here," explains faculty member Paul Cottle, "and make [physics] accessible to all."

Accordingly, the introductory course has undergone multiple iterations in an attempt to establish the best learning environment. Student advising was redesigned to ensure high-quality advice is being given to students; learning is assessed using validated concept inventories, particularly the Force Concept Inventory; and the introductory course is taught by faculty members who have a particular interest in student learning.

The department's care for the skills gained through the major is reflected in the fact that faculty members created their own courses to fulfill two university requirements, communication and computing, rather than letting students take general courses designed for all majors. The teaching culture is supported with hiring decisions that include criteria teaching as well as research accomplishments: "We don't hire people we don't expect to do a good job teaching," explains chair Horst Wahl, "even if they're a super research star."

(3) Strategic teaching assignments at the introductory level have enabled the department to make sure that students encounter enthusiastic, high-quality teachers in their first year. Teaching assignments are made in a typical fashion: The faculty members are polled to see what courses they might like to teach, and the chair and associate chair try to accommodate those requests. Given that certain courses are more popular to teach than others, faculty members who don't get their first choice are promised that their preference will be honored in the future. However, an ongoing challenge is that the same instructors are often "stuck" in the introductory sequence, due to familiarity with these complex courses (such as multi-section or Student-Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP) courses; see below), and the department does not have a formal policy regarding the number of times that a given faculty member can teach a course.

Strategies used at Florida State University

The broad values detailed above have led to the following concrete strategies:

(1) **A one-credit seminar introduces students to the program.** Members of the department's undergraduate committee noticed that students were leaving the program during or after their first year, often with no contact with anyone in the department or with other majors. Informal discussions showed that students weren't aware of what physicists actually *do*, and that they lacked community. Thus, the department instituted Discovering Physics, a one-credit seminar typically taken in the first semester of the first year, which includes an undergraduate panel, a physicist panel, lab tours, a discussion of career paths and graduate school, and resume writing. Students in the course must also interview a professional physicist (in groups of three), report on that interview in class, and discuss what they learned in small groups.

"Nobody wants to major in physics to solve inclined plane problems," explains Dr. Cottle. "This keeps them engaged by involving them in things that they want to learn about." The timing of this course is important for maintaining that engagement, since many students would otherwise not take any physics courses in the first semester of the major while they are fulfilling their calculus prerequisite. This course approach has many other advantages, including exposing students quickly to research (many go on to do a research project with the faculty member they interview) and building community among the cohort. The course was successful enough that it became required for the major.

However, how a good idea such as the Discovering Physics course is implemented can matter as much as the idea itself. When the course gradually devolved into formal faculty presentations about their work, students didn't interact as much. The creator of the course is now working to recapture the original vision and include more student interaction.

(2) **A specialized course offers experience in communication**. In response to the university's oral communication requirement, physics faculty members decided to offer their own communication course (Communication in Physics), usually taken in the junior or senior year. Students are required to give three talks during the course of the semester, either on their own research project or another physics topic. Students produce an outline (which is critiqued), give the talk, and receive anonymous feedback using a peer evaluation rubric.

(3) **Undergraduate research is emphasized and supported.** Over half of the physics and physics and astrophysics majors participate in undergraduate research (usually for course credit), and most of these students write an honors thesis. The above-mentioned courses play a strong role in this success. In Discovering Physics, students are introduced both to the idea that undergraduate research is important, and they meet faculty members with whom they might do that research. In Communication in Physics, many students present their research projects, and so other students "see their classmates doing these cool things," explains Dr. Wahl, and want to get involved themselves.

Students aren't given pre-defined job postings for research opportunities. Rather, they are specifically instructed to look at the websites of professors with whom they would like to work and to knock on their doors, encouraging independence. The department also holds a poster session for student researchers each year, with a monetary prize. While faculty members do not receive formal incentives for mentoring undergraduate research, it is included on their annual evaluations. So far, all students wanting a research project are able to be accommodated, either within the department or at the on-campus National High Magnetic Field Laboratory.

(4) **The introductory sequence has a SCALE-UP option.** The introductory calculus-based sequence (comprised of students across several majors) can be taken in SCALE-UP format, with students working in small groups at tables in two three-hour periods per week, or as a lecture/recitation/laboratory course. While all students are strongly encouraged to take the SCALE-UP version, physics majors are told to enroll in these classes and space is held for them. Within the larger SCALE-UP course, instructors form physics-major-only groups so that they can get to know one another. "Spending six hours a week together builds strong relationships," explains Dr. Cottle, "and helps them to be more durable physics majors." Unsurprisingly, results show that the physics knowledge of students who complete the SCALE-UP course is superior to those who do not.

(5) **An intermediate-level problem solving course better prepares students for the upper division**. Department faculty members noticed that physics majors often did not transition well from the introductory sequence to the majors-only classes, especially Mechanics I. It wasn't clear whether students weren't motivated to do the work, or if students were poorly prepared for the level of rigor. "They assume that since things have been relatively easy for them so far, more advanced work would also be easy," says Dr. Blessing, who typically teaches the course.

So the department established Physics Problem Solving, which is typically taken after the introductory sequence and alongside Intermediate Modern Physics. Students are provided intensive practice in navigating multi-step problems and writing coherent solutions through clear guidelines for presenting solutions, complicated homework problems, and weekly quizzes. The course prepares students mentally for the upper-level courses and helps them build important problem-solving skills.

To become accustomed to talking about physics, students discuss qualitative problems in small groups during class, write up their responses, and critique the responses of other groups. "The students think I'm really mean," says Dr. Blessing, "but then they come back later and thank me." The course also has an important role in building student community: This is the first course since Discovering Physics where students gather with other physics majors.

To help build the cohort, instructors rotate student groups each week. "This course has turned into an excellent predictor of future success in the upper-level courses," says Dr. Blessing. This course gives a much-needed boost to students who come in with weak problem-solving skills, but all students benefit. Indeed, there is such a strong correlation between grades in Physics Problem Solving and the upper-division courses that the former first became required, and then became a prerequisite for Mechanics I and Mathematical Physics.

(6) **Student community is supported through curriculum and a central student lounge.** The undergraduate curriculum committee worked hard to establish a student study lounge with all the typical trappings: tables, computers, a sofa, a refrigerator, and a microwave. Committee members also ensured the space was located centrally, across from the undergraduate administrative office. Whereas that space might have been used for graduate students, the undergraduate curriculum committee argued that the graduate students are integrated into the department regardless of where they sit, but the same is not true of undergraduates. Having the undergraduate students visible has helped them to feel more comfortable stopping by to talk to faculty members, whom they know through Discovering Physics.

"You have to force students to interact," says Dr. Blessing, who directs the undergraduate program. Student interaction is intentionally built in to the Discovering Physics and Physics Problem Solving courses, as well as the SCALE-UP version of the introductory course, where majors are clustered within a few groups within the large, mostly non-majors course.

What is unique about Florida State University?

Florida State University is a large public university with a focus on undergraduate education as well as research. The proximity of the National High Magnetic Field Laboratory provides many research opportunities for undergraduates and graduate students alike. Thus, other institutions may need to adapt some of the strategies in this case study to their situations. These factors do not mean that it is impossible for a different type of institution to use these strategies, but it is important to be aware of local strengths and barriers to change when adapting ideas from other institutions.

For more information

Contact: Susan Blessing, chair of the Undergraduate Affairs Committee, blessing@hep.fsu.edu	**Department website:** http://www.physics.fsu.edu
Course catalog: http://registrar.fsu.edu/bulletin/undergraduate/departments/physics/	**Student-Centered Active Learning Environments for Undergraduate Physics (SCALE-UP):** https://www.ncsu.edu/per/scaleup.html
Sources: Interviews with Horst Wahl, Susan Blessing, Paul Cottle, and Winston Roberts.	

St. Mary's College of Maryland Case Study

About St. Mary's College of Maryland

- Location: Southeastern Maryland
- Type of institution: Four-year liberal arts institution and public honors college
- College ranking: 93rd among national liberal arts colleges (*U.S. News & World Report*)
- Physics faculty: 5 tenure-track
- Students enrolled: 1,800 (college as a whole); 35 (physics majors declared)
- Physics bachelor's degrees awarded per year: 13
- Physics degree offered: B.A. in physics with required concentrations in fundamentals or applied physics. Double-degree program in mechanical engineering in partnership with the University of Maryland.

What can we learn from St. Mary's College of Maryland? *Embrace experimentation and build on the work of others.*

St. Mary's College of Maryland (SMCM) has a small physics department that is engaged in an impressive array of activities, due in large part to an intensive **culture of experimentation and collaboration**, in which the faculty and chair **continually learn** both from each other and from national efforts. These ideas have led to productive approaches, such as faculty members working together to take responsibility for the program, as well as high-quality instruction for students. This has in turn led to good student learning outcomes and graduation rates (especially for underrepresented minorities), as well as numerous external grants, including a recent $1-million award. "We want high-quality students to apply to SMCM *because* of the physics program," says department chair Josh Grossman, quoting the department's mission statement.

The faculty and chair offer the following advice to other departments:

> "Set high standards for yourself."
> "Don't rely on external forces; take responsibility for making changes yourself."
> "Don't worry about the budget. If you have a good idea, try it out. If it works, people will support it."
> "Just because something was tried in the (non-recent) past doesn't mean it won't work now!"

How did the St. Mary's College of Maryland physics department get to where it is today?

The long-time chair had worked to support a vision of change for the department since the early 2000s, with the aim of increasing enrollments and graduation rates. Four key elements of the department's approach include the following, described in more detail below:

(1) The department took responsibility for developing a strong program.
(2) The faculty members see themselves as a cohesive, supportive community.
(3) Experimentation is embraced and supported.
(4) Faculty members continually learn from others.

(1) The department took responsibility for developing a strong program. When needing to improve enrollments, faculty members were especially struck by the 2003 Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) report, which advised faculty members to be self-reliant as a department, rather than complain and wait for the administration to guarantee funding and students. This local responsibility is unusually explicit within the St. Mary's department (several faculty members spontaneously mentioned this guiding principle in interviews.) For example, faculty members went to college fairs and high schools to vie for the best incoming students, developed proposals for national funding to help support the program, and developed many strategies (detailed later in the report) to support the program.

(2) The faculty see themselves as a cohesive, supportive community. "All for one and one for all," says long-time former chair Charles Adler. Department faculty members cooperate, rather than compete, by, for example, not competing for students, observing each other's classes to get new ideas, and making decisions together as a collective. There is a pervasive sense that the department is stronger when all members engage and are successful.

This collective spirit is particularly evident in the mentoring of junior faculty, who are protected from politics and excessive service, nominated for teaching awards, and given advice aimed at helping them attain tenure (such as demonstrating concrete teaching achievements). When the department's first female faculty member was hired, senior faculty members took time to learn about the challenges that female faculty members face, so that she would be supported. The successful tenure of any one faculty member is seen as a reflection on the department as a whole. "I'm really grateful," says professor Erin De Pree, speaking of the mentoring she received as a junior faculty member. "This is very valuable and rare." She also works to perpetuate this same culture: "I make sure to tell others that I think the chair is doing a really great job." She acknowledges that interpersonal relationships can be tough for physicists. "We've done a lot of learning as a department."

(3) Experimentation is embraced and supported across the program. "You have to be willing to say yes more than no," Dr. Adler explains. "If it's a decent idea, then go for it." For example, when a junior faculty member suggested reordering the topics in the introductory sequence, Dr. Adler gave it the green light. "I was struck by people's confidence in me," that faculty member later said.

In another example, a new structure for the introductory sequence was formalized after a fortunate mistake, when there was not room in the introductory course to accommodate all majors. The department decided to take the opportunity to try offering a separate course for the physics majors. When assessments showed improvements in student learning and satisfaction, the department formalized the structure. Teaching innovations are also common, and faculty members learn new ideas through conferences and journals, and share with each other.

This type of educational experimentation is supported in several ways: (1) Faculty members' annual reviews ask for new approaches they tried, and the chair emphasizes reflective teaching; (2) The department uses validated measures of student learning such as the Force Concept Inventory (FCI) to objectively assess educational outcomes; and (3) If student evaluations drop when an innovation is implemented, FCI results are used as an alternative measure to argue for teaching excellence. Additionally, faculty members were able to show, using local data aggregated by course, that there is no correlation between student evaluations and FCI results, further supporting the case for not overly weighting low student evaluations.

Perhaps most importantly, the two most recent chairs and their faculty embrace experimentation and give license to new ideas. "It's much easier because we're all doing it," says Dr. De Pree, "rather than being expected to do it by yourself and sustain it by yourself."

(4) The department continually learns from others to support this experimentation. Several national reports have guided the department's efforts, including SPIN-UP (which faculty members discussed at length, and used to convince administration of their needs), and the American Institute of Physics (AIP) Career Pathways Project (which inspired a career curriculum unit embedded in the third-semester introductory course). Faculty members are encouraged to attend teaching conferences, and their courses are covered while they travel. Most faculty members have attended the AAPT-sponsored Workshops for New Physics and Astronomy Faculty, providing a common set of knowledge in physics pedagogy and teaching, as well as a continual infusion of new ideas. Additionally, most of the department's innovations, including maintaining an alumni database, creating an alumni event, trying new curricular innovations, and developing mission statements, were adapted from other institutions.

Strategies used at St. Mary's College of Maryland

The above broad values have led to the following concrete strategies:

(1) A separate version of the introductory course is offered for students interested in physics. Fundamentals of Physics, intended for physics-interested students, is a three-semester sequence (mechanics / modern / electricity and magnetism), using a SCALE-UP approach. Modern physics is included in the second semester in order to create excitement among students, and electricity and magnetism is put off until the third semester so that students have time to get more mathematics courses under their belts. Activities pertaining to physics careers are also embedded in the third semester (see below).

The department has found it very helpful to have a separate course for potential majors, both because a strong cohort and community can be built among students interested in physics, and so the course can be better targeted to the population. Prior to the split, students in the General Physics course were a mixture of first-year students interested in physics and junior/senior chemistry and biochemistry majors taking the course to fill a requirement, which was not particularly supportive for the first-year students. The atmosphere in the new Fundamentals of Physics is more enthusiastic, and first-year students can get more necessary mentoring. "I invest more in that course," both in terms of mentoring and forming relationships with students, says Dr. De Pree. "I assume the juniors in the other course are getting mentored in their own departments."

Since the new Fundamentals of Physics course was created, student learning gains (as measured by the FCI) and overall student satisfaction have increased, suggesting that splitting the courses created a better experience for both majors and non-majors.

(2) A career curriculum is embedded in the introductory course. Realizing that students lacked knowledge and skills related to careers, faculty members embedded a series of weekly assignments (which use recommendations from the AIP Career Pathways Project) into the third semester of Fundamentals of Physics (see above). Topics include exploring careers and graduate programs, finding summer research opportunities, drafting resumes, and networking, all of which involve students practicing what they learn. For example, students are required to research, and write a letter of application for, an internship. The assignments are rather time intensive, and so also serve as a measure of students' commitment to the major. Once the goals for the assignments were made more explicit to students—that these activities are part of the practice of physics—students became receptive to the assignments. One measure of success is that the number of students engaged in research and internships jumped from around 50% to around 90%, often in the first semester of the sophomore year, since they must develop an application letter as part of that curriculum.

(3) **The department uses a wide variety of physics-education-research-based pedagogies.** Many faculty members have attended the AAPT-sponsored Workshop for New Faculty in Physics and Astronomy and are familiar with a wide variety of innovations. Given the culture of experimentation and supportive collaboration in the department (see above), this has led to the use of an impressive number of innovations, including Just-in-Time Teaching, Peer Instruction, Tutorials in Introductory Physics, SCALE-UP, cooperative group problem solving, various group work, intentional group selection, values affirmation to combat stereotype threat, discussion of fixed/growth mindset, reflective writing, chapter summaries, model-based reasoning in laboratories, Emerging Scholars Program, Physlets, standards-based grading with voice, and research mentoring contracts. Additionally, the department has drawn on research at the program level through the SPIN-UP report and the AIP Careers Pathway Project. "We say that if we're going to do good teaching of science, we're going to base it on actual science," says Dr. De Pree.

(4) **An Emerging Scholars Program supports under-represented minorities.** An Emerging Scholars Program (ESP; funded by a National Science Foundation S-STEM grant and based on a program designed by Uri Treisman at the University of California, Berkeley) targets underrepresented and at-risk groups, including racial and ethnic minorities, women, students with low socioeconomic status, first-generation college students, and students taking calculus concurrently with physics. These students meet once a week to work on challenge programs in small groups, and to discuss other aspects of the major, such as study habits. This challenging but low-stakes environment helps students form social networks among peers and build relationships with faculty members, which they can turn to throughout their degree programs. Nationwide, ESPs typically help students achieve and persist at rates higher than their peers outside the program.

(5) **An alumni/ae event is hosted annually.** The department has recently begun to offer a half-day alumni/ae gathering, which includes panel discussions and networking, and is focused around a topic (e.g., the 2015 International Year of Light). The event, which was inspired by similar events at Colorado School of Mines, is intended to provide networking opportunities for alumni/ae, faculty, and students, help students and faculty members to learn about career options and pathways, serve as a recruiting tool, and gain respect with the administration.

(6) **The department keeps track of alumni.** Inspired by work presented at a conference on institutional reporting, the department maintains an alumni database (including information such as name, email address, year of degree, major, type of career path, current and past positions, and address). This database is maintained locally by the chair and another faculty member, which is a manageable job for a small department. They actively seek out information on alumni through the university alumni office, Facebook, LinkedIn, Google, and personal and department communications. This database has proven very valuable in tailoring the St. Mary's degree program (e.g., faculty members take into account that 70% of their students do not go directly on to physics graduate programs), as well as justifying or celebrating various elements of the program to administrators or outside funders (e.g., that 90% of students do continue on to a STEM-related career).

What is unique about St. Mary's College of Maryland?

St. Mary's is an unusual small institution, in that it is a *public* liberal arts college, and was also designated as the state's honors college. Thus, the student body is quite strong, and students often take a range of courses and entertain a variety of interests, including multiple majors. The college's mission includes "enhancing accessibility, affordability, and diversity," which gives it a particular motivation to serve underrepresented populations. Thus, faculty members at institutions that are larger or more research focused may need to consider which strategies best suit their contexts. These factors do not mean that it is impossible for a different type of institution to use the strategies employed at St. Mary's College of Maryland – but it is important to be aware of the local strengths and barriers to change when adapting ideas from other institutions.

For more information

Contact: Josh Grossman, department chair, jmgrossman@smcm.edu	**Department website:** http://www.smcm.edu/physics/
Course catalog: http://www.smcm.edu/physics/academic-offerings/what-you-learn/courses/	**Facebook group:** https://www.facebook.com/groups/SMCMPhysics
Sources: Interviews with Josh Grossman, Charles Adler, and Erin De Pree.	

University of California, Davis Case Study

About University of California, Davis

- Location: Central California
- Type of institution: Public research university, University of California system
- College ranking: 11th among national public universities (*U.S. News & World Report*)
- Physics faculty: 46 tenure-track faculty plus 2 lecturers
- Students enrolled: 25,000 (university as a whole), 250 (physics majors declared)
- Physics bachelor's degrees awarded per year: 40–50
- Physics degrees offered: B.A., B.S. with optional emphasis in astrophysics, applied physics B.S. (with emphasis in computational, physical electronics, chemical physics, material science, geophysics, oceanography, or atmospheric physics), and a joint master's program resulting in a B.S. in physical electronics and an M.S. in electrical engineering in 5 years.

What can we learn from University of California, Davis? *Focus on exciting science.*

The University of California, Davis (UC Davis) physics department has nearly doubled its population of majors in the past decade, and 25% of its majors are women. One of the primary foci of the department's undergraduate program is **exciting science**. Additionally, the department focuses on **preparing students for STEM careers**, by providing professional skills (such as writing and job-seeking skills), insight into physics careers, and research opportunities.

The undergraduate curriculum provides opportunities for specialization in multiple degree tracks and capstone courses, plus multidisciplinary opportunities within several applied degree tracks. Students engage in authentic research experiences both, as electives and as part of required advanced labs. Students gain insight into the multitude of careers available to them through a seminar series. Together, these elements create genuine excitement and sense of purpose among students.

How did UC Davis get to where it is today?

The key element of UC Davis' approach is a **commitment to undergraduate education**. This spirit pervades the department, and students feel that faculty members are engaged and care about teaching. As a larger, research-focused institution, UC Davis relies on the committee structure to make recommendations for its undergraduate program. A dedicated cohort of faculty members and instructors has driven many of the efforts, and their enthusiasm has "filtered up" to the department at large. As a mark of the importance of the undergraduate experience, core courses are often assigned to these dedicated individuals.

Strategies used at UC Davis

This commitment to the students has driven the following concrete strategies:

(1) The honors introductory course helps to form a strong student cohort. Students are able to choose to take either the typical calculus-based course (Physics 9, enrollment near 200, which includes engineering physics majors) or an honors course (Physics 9H, enrollment around 30). Both courses use investigative laboratories such as the Investigative Science Learning Environment (ISLE), which are based on physics education research.

Physics majors are advised to enroll in Physics 9H, which is a smaller course with a combined laboratory/recitation section. This has several advantages: (1) Most students in the course (about 80%) are physics majors, so a strong student cohort is formed; (2) The course is smaller, with just one section and a single teaching assistant (as opposed to multiple sections in the larger course), helping students get to know each other, the teaching assistant, and the instructor; (3) The combined lab/recitation section provides for more flexibility in how this time is used; and (4) The curriculum can be better tailored to the interests of physics students. Additionally, the course content addresses 20th-century topics such as special relativity and quantum mechanics earlier, and in the final quarter it includes tours of laboratories and special topics.

(2) Emphasis on undergraduate research prepares students for diverse careers, and injects excitement and purpose into the degree. About half the department's majors do some form of undergraduate research, either for course credit, a senior or honors thesis, or pay during the summer. There is a culture among faculty members of welcoming students into their labs and helping them develop career skills. The department strongly supports student engagement in research: Advisors encourage students to get involved in research, students are introduced to the research opportunities in one of the career seminars, and faculty members can earn substantial credit towards course release by advising undergraduate research (20 student-quarters of undergraduate advising earns one quarter's worth of course release).

The campus Physics Club offers opportunities for students to talk about their research, supporting a student culture of research engagement and spreading excitement about their work. "Research tends to focus students' thoughts on why they're taking physics, and what they will do with it," says long-term instructor Randy Harris. At a large university like UC Davis, research experiences also offer a chance for individualized interactions with faculty members and graduate students. Additionally, research experience makes students very attractive to employers, especially for students not planning to attend graduate school.

(3) Advanced Lab course provides authentic research and communication experiences. The Advanced Lab course is seen as a rite of passage among students. Rather than a potpourri of classic experiments, this course requires students to complete two experiments from scratch, including authentic investigation, an experimental write-up in the style of *Physical Review*, critique by faculty members, and resubmission of the final report. The course fulfills a university writing requirement, a testament to its unusual structure.

To help build students up to this challenging task, the course also requires a shorter, non-elective experiment, and three required labs. Intentional errors are introduced into the apparatus before class, helping students to learn essential troubleshooting skills. The Advanced Lab is not required, but those who opt for an alternative laboratory course will encounter similar experiences. A recent syllabus can be seen at http://122.physics.ucdavis.edu.

(4) Two seminar courses give students an introduction to physics careers and professional skills. These optional seminar courses are offered every fall and spring, and about half of physics majors enroll. However, the seminars are advertised widely in the department, and students are encouraged to drop into seminars on a topic of interest, which many do. The Careers in Physics seminar provides an overview of the basics of preparing for a career, such as scholarships, application letters, personal statements, the Graduate Record Examinations , and the variety of careers available. UC Davis faculty members also give short presentations about their research, giving students a sense of undergraduate research opportunities and facilitating future collaborations.

The alumni career seminar invites previous graduates and professional physicists outside academia to come and talk about what students can do with a degree in physics (past speakers have represented companies such as Microsoft and DreamWorks). This seminar provides insight into physics careers, as well as networking opportunities with alumni. Students tend to take these courses early in the curriculum, providing clearer direction during the rest of their degree programs.

(5) Strong tutoring and advising helps keep students on track. In addition to a dedicated staff advisor, two instructors do the bulk of faculty advising. These individuals have a strong commitment to undergraduate education (one is the undergraduate curriculum chair; the other is advisor to the Physics Club) and so are well connected to the student experience. This centralized advising provides continuity and coherence, and allows the department to get a clear picture of what is working and what is not working in the program. Additionally, students have free tutoring opportunities at both the lower-division (run by the Physics Club) and upper-division (run by the student-initiated group H-bar, which is staffed by graduate students) levels. The upper-division tutoring has been particularly helpful for the department's many transfer students, who enter as juniors and are not well connected to the student community.

(6) A strong student community is supported from many angles. Students often say that they feel very welcome in the department, and that they feel part of a strong community. This community is created in several ways. First, the Physics Club is very active; it hosts outreach and recruiting events, provides a venue for students to talk about their research, and supports lower-division tutoring. The club is advised by an energetic faculty member who also teaches the first-year course and is one of the primary faculty advisors, and so is well known by and connected to the students. There is also a dedicated student space, and activities held in that space draw students to it. Social events provide a chance for student and faculty community: In the fall, an undergraduate pizza social provides an informal gathering opportunity, and the spring picnic for undergraduates honors the departing undergraduates.

The department also hosts several events specifically focused on underrepresented minorities. There are a few events focused on women each year, including quarterly lunches, and weekly Diversity and Inclusion in Physics meetings provide presentations and discussions of diversity issues and how to address them in the department. A WordPress blog for that meeting is available: https://davisdip.wordpress.com.

What is unique about UC Davis?

UC Davis is a Highest Research Activity (formerly called "R1") university, with a large student and faculty body. About half of undergraduate majors pursue a graduate degree (a relatively high percentage). UC Davis is part of the large University of California system, and operates on a quarter system. Due to a state mandate whereby some community college students are guaranteed entrance to a UC, many students transfer from two-year colleges to UC Davis.

These factors pose both opportunities and constraints. Thus, institutions that are smaller, have fewer transfer students, are not part of a substantial network of universities, operate on a semester system, or have students who do not typically pursue graduate degrees, will need to adapt these strategies to their situations. These factors do not mean that it is impossible for a different type of institution to use the strategies employed at UC Davis – but it is important to be aware of the local strengths and barriers to change when adapting ideas from other institutions.

For more information

Contact: Patricia Boeshaar, undergraduate curriculum chair, Boeshaar@physics.ucdavis.edu	**Department website:** http://physics.ucdavis.edu
Course catalog: http://physics.ucdavis.edu/academics/physics-courses	**Investigative Science Learning Environment (ISLE):** http://www.islephysics.net
Advanced Laboratory Physics Association (ALPHA): http://www.advlab.org	
Sources: AIP Career Pathways Project documentation; interviews with Patricia Boeshaar, Randy Harris, Rena Zieve, and Lori Lubin.	

University of Wisconsin–LaCrosse Case Study

About University of Wisconsin-La Crosse

- Location: Western Wisconsin
- Type of institution: Four-year, undergraduate-only institution
- College ranking: 29th among regional universities in the Midwest (*U.S. News & World Report*)
- Physics faculty: 10 tenure-track, 3 full-time instructional staff
- Students enrolled: 10,000 (college as a whole); 160 (physics majors declared)
- Physics bachelor's degrees awarded per year: 27 (ranked 5th in number of degrees awarded nationwide among bachelor's-only departments averaging 10 or more degrees per year, AIP, 2015)
- Physics degrees offered: B.A. or B.S. with optional concentration or emphasis in astronomy, biomedical, business, computational, or optics, as well as a major in physics education (leading to state licensure). Dual-degree 3-2 programs available in engineering and physical therapy, as well as a second major in general science education.

What can we learn from University of Wisconsin–LaCrosse? *Students come first.*

The vision of the physics faculty members at University of Wisconsin–LaCrosse (UW-La Crosse) is that **students come first**. This undergraduate-serving four-year college devotes substantial resources and attention to supporting its students. The result of the constellation of strategies the physics faculty members have employed is astounding: The department has gone from graduating less than one physics major per year in the early 1990s to graduating 27 per year, and now the small 13-faculty team supports 160 declared physics majors.

The department creates an attractive major through flexible options and an approachable faculty, drawing large numbers of students. Once those students enroll, they are inducted into a vibrant student community, connected directly to faculty members, and given intensive individual advising and support. Thus, students stick with the major even when the going gets tough. The department is deeply connected and responsive to the student needs through proactive, mandatory advising, and a long-term faculty-centered assessment plan that provides reflective feedback, allowing for a culture of continuous self-evaluation and improvement.

The department chair, Gubbi Sudhakaran, offers the following advice to other departments:

> "Students come first, but always take care of your faculty."
> "Give the administration what they want."
> "Don't take anything personally; it will stress you out."

How did the UW-La Crosse physics department get where it is today?

When the department was on the brink of closure in the early 1990s, two faculty members were brought in to revitalize the program, one of whom, Dr. Sudhakaran, has remained chair since the mid 1990s. With the goal of attracting, retaining, and graduating large numbers of students, Dr. Sudhakaran created many structures that persist today, such as a wide variety of undergraduate degree specializations, a dual-degree engineering program, and a supportive and diverse faculty built through strategic hiring. A sensitive leader, Dr. Sudhakaran has attended carefully to faculty buy-in to the process, and as a result is deeply trusted by his faculty.

Three key elements of the department's approach are the following, described in more detail below:

(1) Strong, ambitious leadership
(2) Assessment that is led by the faculty and valued by the chair.
(3) A department that is visible to the university administration and the broader community.

(1) **Strong, ambitious leadership** in the department has been critical to success. As long-term chair, Dr. Sudhakaran has been able to build a strong department over time, providing consistent leadership. He exhibits many aspects of strong leaders, including careful selection of new faculty members, mentoring of faculty members, securing of faculty buy-in and support of new structures, setting of annual goals for his faculty members, and initiation of collaborations across campus. He works closely with administrators and has earned their trust over time.

Dr. Sudhakaran is also quite ambitious and has clear vision for the department. Even without administrative pressure to do so, he worked with faculty members to institute a five-year plan to guide departmental decisions, and created an assessment committee to evaluate progress toward the established goals.

(2) **Assessment is valued by the chair, and led by the faculty**, providing the department with rich data to guide decision-making and programs. "You can have a good program, but if you don't have assessment, you don't know what you're getting," Dr. Sudhakaran

says. He established an assessment committee (see below) with responsibility for carrying out assessment, which is discussed annually in a faculty meeting. This public discussion of departmental data has led to positive program changes. For instance, faculty members realized they needed to more explicitly teach communication skills, and thus added two prepared talks in each upper-level class.

Faculty members can also use the feedback to make changes to individual courses, resulting in a highly aligned and consistent curriculum. Additionally, Sudhakaran uses multiple channels for feedback, and engages in many conversations with students, other departments, graduate schools, and partners in the 3-2 program; he also gathers data through alumni surveys. These informal feedback mechanisms have led to other program changes, such as the addition of engineering-focused classical mechanics and thermodynamics courses to better meet the needs of dual-degree students.

(3) **The department is made visible to the university administration and the broader community,** providing financial resources, as well as the power of reputation. The chair keeps an eye on the kinds of numbers that the administration values, such as student enrollments and credit hours. He also actively promotes the visibility of the department in the community and campus through public events and the media. For example, the department hosts a Nobel Laureate every year in its Distinguished Lecture Series, and uses outreach as a long-term recruiting tool with younger children.

These efforts increase their regional draw, and have won over the support of the administration, which has given the department tangible resources such as space and funding to support its mission. For example, Sudhakaran might ask the dean for the target number of student credit hours, but then request that he "give me the flexibility to get there in the way that I see best." The number of majors has steadily increased, and now the reputation of the program makes it easier to maintain strong enrollments.

Strategies used at UW-La Crosse

These broad values have led to the following concrete strategies:

(1) **A faculty assessment committee provides ongoing opportunity for reflection on the program and courses.** The physics department chair instituted a faculty-led assessment committee, which is responsible for identifying which courses will be used to assess student achievement of program-level learning goals (e.g., physics content, communication, lab skills, and data analysis). Faculty members can choose how to assess these goals in their courses, using a variety of assessments such as concept inventories and student feedback. The department's Capstone in Physics course offers a final assessment opportunity for many of these program goals. These data are compiled into a report that includes longitudinal comparisons; the report is presented at an annual faculty meeting. This ensures that the data actually affect the department, rather than simply going into a binder on a shelf and demotivating faculty participation.

(2) **Advising is rigorous, required, and intensive**. It might seem odd to call advising "rigorous," but UW-La Crosse's approach to advising is somewhat unusual. While the small number of astronomy-emphasis and physics education students are advised by other faculty members, the chair advises the rest of the 160 physics majors each semester. This 20-minute advising session is *required*: A hold is placed on the student's registration pending this appointment. Three weeks each semester is blocked out of the chair's schedule to allow for advising. This advising is important on a few fronts: The chair becomes deeply connected with students' needs and experience, and struggling students are more likely to stay in the major.

(3) **Multiple degree tracks are offered.** Dr. Sudhakaran sees the multiple degree tracks as a strong recruiting tool, even if some specializations are not used by many students. Students feel that they'll have many options, and certain employment, if they stay with the physics major. Since career options in engineering are more commonly known than are options in physics, the 3-2 dual-degree engineering program is quite popular. Dr. Sudhakaran reports that it's not unusual for a student to switch into pure physics once they become more aware of the various careers the major can prepare them for. The diverse faculty pool has made it possible to offer such varied concentrations.

(4) **Students learn about careers in a first-year career seminar.** The department offers a one-credit seminar in both fall and spring for freshmen, most of whom take advantage of the opportunity. This seminar includes research talks by various faculty members, and discusses various career and degree options. Students must submit a one-page paper on one talk, and sign in at seminars for credit. This seminar thus gives a preview of the physics degree, but is also an important community-building opportunity for the student cohort. This helps students feel that they belong in the department, and they are more likely to stay with the major when they begin to have trouble. Students are also introduced to faculty members and to the chair, who encourages students to come to see him if they are having trouble—which many do.

(5) **Students are inducted into a community, and feel cared for**. In addition to the first-year career seminar, students connect with others in their cohort in an active first-year calculus-based combined lecture/lab course. All majors take physics in their first year (either calculus-based or algebra-based, depending on their math placement), creating an early sense of identity. There is an active Physics Club and a Women in Physics Club. The two clubs co-organize a department picnic every semester, and the department is credited with having a particularly "homey" feel. Students feel that faculty members are approachable, and the intensive advising program makes sure that students don't get off track or feel lost.

(6) **Undergraduate research is valued and supported.** The program boasts that students can get undergraduate research experience, even at an undergraduate-only institution, and this serves as a valuable recruitment tool. About one-quarter of students do some undergraduate research. Faculty members are provided a three-credit teaching load for supervising undergraduate research, and some students continue projects during the summer for a stipend.

What is unique about UW-La Crosse?

UW-La Crosse is a primarily undergraduate-serving institution, and this allows the faculty to focus on undergraduate education and devote substantial amounts of time, attention, and money to serving this population. Faculty members maintain active research programs, allowing for undergraduate research opportunities. The department is small and relatively young, allowing for a cohesive culture that was strategically created by the long-time chair. The department benefits from a single, long-time chair who is repeatedly elected by the faculty, and who has strong vision, ambition, connection to the administration and community, and leadership skills.

Larger institutions with substantial turnover of the chair and more strongly competing research priorities will need to adapt these strategies at their situations. These factors do not mean that it is impossible for a different type of institution to use the strategies employed at UW-La Crosse – but it is important to be aware of the local strengths and barriers to change when adapting ideas from other institutions.

For more information

Contact: Gubbi Sudhakaran ("Sudha"), department chair, gsudhakaran@uwlax.edu	**Department website:** https://www.uwlax.edu/physics/
Course catalog: https://www.uwlax.edu/Physics/Courses/	
Sources: AIP Career Pathways Project documentation; interviews with Gubbi Sudhakaran, Jennifer Docktor, and Eric Gansen.	

Appendix 2: J-TUPP Study of Physics Majors in the Workforce

Study Description

The Joint Task Force on Undergraduate Physics Programs (J-TUPP) requested that Dr. Rachel E. Scherr (Seattle Pacific University) undertake an interview study to better understand how well students graduating with a physics degree are prepared for work in jobs in industry, technology, business, the military, and other career paths outside of academia or teaching. Dr. Scherr conducted this study in January–March 2015, with interviews with two populations:

- Physics bachelor's degree holders who had been hired into jobs in industry, technology, business, or the military in the last 1–5 years
- Hiring managers: Personnel who make hiring decisions at such organizations, including hiring physics graduates

Study Participants

To identify physics bachelor's degree holders now working in industry, American Physical Society (APS) and American Association of Physics Teachers (AAPT) liaisons contacted faculty at physics departments known to have significant numbers of graduates who worked in industry. Physics faculty provided contact information for 32 students, all of whom were invited to participate in the study. Fourteen were interviewed, for a response rate of about 44%.

Of the graduates, 10/14 work in industrial/scientific settings where they contribute to the design, construction, or testing of commercial products such as optoelectronics, power amplifiers for satellites, custom pulse power supplies, wire bonders and die bonders, electrical systems for buildings, or airplanes. Three of 14 design or develop software for businesses (including a shipping supplier, a bank, and an electronic health records management company). One of 14 works in military defense. Though most were recent hires (in the last 1–5 years), some had been in the workforce much longer; these were not removed from the study.

Hiring managers were identified in three ways: (1) During their interviews, physics graduates were asked to provide contact information for the person who had hired them. (2) The J-TUPP chairs and society liaisons contacted the same faculty members who recommended former students and asked them to identify any employers who had hired their former students. (3) Two J-TUPP task force members who had personal experience hiring physics undergraduates were invited to participate. In total, 10 hiring managers were invited to participate in the study. Five were interviewed, for a response rate of 50%.

Of the hiring managers, 3/5 work in industrial/scientific settings (laser engineering, custom pulse power supplies, petrochemical testing), 1/5 in business (electronic health records management), and 1/5 in a nonprofit federally funded research center focused on national security.

Participants mostly offered brief, direct responses to the interview questions.

Interviews With Physics Graduates

Physics graduates were interviewed according to the following protocol:

(1) What job are you now doing?
(2) What did you learn in your physics degree program that prepared you for this job?
(3) What do you wish you had learned while majoring in physics that would have improved your current job or your career trajectory?
(4) Would you be able to put me in touch with the person who hired you so that we can get that person's perspective on hiring physics majors?
(5) Is there anything you want to add, or any questions you want to ask me?

Participants' responses to question 1 are summarized in "Study Participants," above. Question 4 was used to identify hiring managers to interview. Responses to questions 2 and 3 are summarized below.

What do physics graduates report having learned in their degree program that prepared them for their current job?

In reflecting on what they learned in their degree programs that prepared them for their current jobs, participants tended to either recount specific disciplinary preparation, or preparation in "problem-solving." Participants offered various other reflections as well, including what they learned about research, teaching, or programming.

Physics

Many participants reported on specific disciplinary preparation that they had received in their degree programs that they needed for their current jobs. Most participants mentioned specific disciplinary preparation in electricity and magnetism, including the field of a wire, circuits, electronics, electromagnetic effects on equipment, and the operation of resistors and diodes. One participant reported that his physics degree made him "cross-functional" in a disciplinary sense, touching on the foundations of all the different engineering disciplines so that he can communicate easily even with chemical or biomedical engineers. Another said that "the interesting thing about physics among the other sciences is that it is so broad," with applications at scales from atoms to planets; he felt that this prepared him for a business "where you bounce back and forth from detailed implementation to big-picture goals."

A few participants mentioned how much the quality of teaching in their undergraduate degree programs had affected their disciplinary preparation and therefore their career readiness. One recalled unhappily that the quality of teaching had been "uneven," which left him less well prepared for his current job than he would have hoped. A graduate of the University of Washington said that "the tutorial system" was "hands-down the most useful part" of his physics major, especially for its emphasis on proportional reasoning with physics equations. The rest of the course emphasized algorithmic application of equations, which is of no use to him in his current job.

Problem solving

Many participants reported that their physics degree programs taught them problem solving. One went so far as to say, "A physics degree is a degree in problem solving." Another said that his workplace strength is that "I'm a physicist and I can solve the problem that you have starting at a defined point in the system."

The term "problem solving" seemed to mean different things to different participants. Many interviewees associated problem solving with breaking down a complex problem into its component parts and solving one part at a time, consistent with one participant's statement that "physics is about how large systems work together that have a lot of parts." Others associated problem solving more with troubleshooting – tracing the possible origins of errors or undesirable outcomes in a complex integrated system of software and hardware. Still others associated problem solving especially with novelty, identifying physicists as "expert at learning things you don't know anything about" and valuing their own ability to approach a problem "from scratch" without comprehensive expertise. Another group of participants saw problem solving in almost the opposite way, as developing (and then sticking to) reliable processes to achieve a desired outcome consistently and efficiently.

Other

Some participants stated that research internships had provided them with important preparation for their current jobs. One said her undergraduate research experience had trained her to think carefully and logically about what constitutes a good experiment. Another credited his research internship with teaching him how to collaborate with diverse colleagues. One participant who works in industry was particularly appreciative of a semester she spent interning in that same industry.

A couple of participants mentioned that the teaching experience they had as undergraduates was valuable for their jobs, even though they are not teachers. One physics graduate who now runs his own business valued his experience as a tutor, explaining, "I have a lot of children in my company and I need to teach them things." Another especially appreciated his exposure to PhysTEC, saying that having faculty promote high school teaching as a career opened the conversation more generally about physics careers not requiring graduate school. He stated, "It's almost like you get your bachelor's and they say okay, you're not done, now go to graduate school," but as a Learning Assistant, he learned that there is a wider world of options.

Several participants reported experience with programming, computational physics, or numerical analysis that was especially valuable for them. One participant said computational physics helped him understand mathematical modeling and introduced him to programming languages.

One participant colorfully recalled how much he disliked being forced to work in groups as an undergraduate, and how valuable that experience of teamwork has been for him in his job. "To have a professor put me in a group with someone I hated, that was very useful," he said; "That's how it is in the real world. I understood it only later that actually he did a good thing."

One participant felt that the greatest value of his physics degree came from the relationship of physics to math. Learning the two together taught him that any subject area has both its content and the language in which that content is expressed. Each business, for example, has a programming language, the vocabulary of the industry, or a "general syntactic jargon" that is not the content of the business, but is the language in which the business is conducted. This participant felt that physics was the disciplinary area most suited to teaching the distinction between content and language.

What do physics graduates wish they had learned while majoring in physics that would have improved their current jobs or their career trajectories?

In reflecting on what they wish they had learned in their physics degree programs, physics graduates emphasized programming and experience in applied physics or industry settings. Some wish they had learned more about the marketability of a physics degree. Others wish they had recognized earlier that physics culture discriminates inappropriately against some students who could excel in physics.

Programming

By far the most common thing that participants wish they could have learned in their degree programs was programming. Participants almost universally perceive programming skills as highly valued in the job market. One said, "Programming is everything." Many wish they could have taken more courses in numerical analysis, computational physics, or computer science. Specific languages that participants wish they had learned include MatLab, Python, Java, C#, C++, Visual Basic, and CAD packages. Though participants especially wish they could have learned whichever programming language is relevant to their current jobs, they also recognized that general exposure to programming is helpful for learning any programming language later. One participant warned that the analysis packages used in academic labs (typically Mathematica and LaTeX) are not common in industry (MatLab is more typical).

Experience in applied physics or industry settings

The second most common thing that participants wish they could have learned in their degree program is the set of skills associated with internships in applied physics or industry settings. Many wish they could have had more hands-on experience with designing, building, or troubleshooting real equipment themselves. They see their physics degree programs as having mainly supported theoretical design and analysis, whereas the skills they need now are more applied. One said, "Companies want you to solve the problem that they have, not analyze something in the abstract."

Several participants saw this deficit as particularly damaging because they are competing with engineers for jobs. One participant said that because he has never designed and built something himself, he's "not really qualified for a straight engineering job." One participant said that "when companies hire engineers they know what they're going to get, but when they hire physics majors they don't know what they're going to get," because programs are both theoretical and different in different departments; he went on to get an engineering degree after his physics degree. Another said that at job-hunting sites like monster.com, searches on "physics" or "physicist" get very few hits, while engineering searches yield many results; he had a hard time finding work until he tailored his résumé to emphasize his engineering-like experience. Other participants felt that they had missed out on something they now love; one speculated that students gravitate to theory "because it doesn't break," but has since found that "there's more joy to seeing something built."

Participants suggested various means by which physics degree programs could provide industry-relevant experiences. Participants see internships and other collaborations with industry as the most straightforward route. Some wished for electives in engineering or other applied topics such as medical physics. Senior design projects (with an applied emphasis) and even hobby projects (such as learning about computing with a Raspberry Pi) are also seen as potentially relevant.

The marketability of skills inherent in a physics degree

Several participants wished they could have learned earlier that a physics degree includes many different marketable skills. One said she "wishes she would have known better what kinds of jobs you can get with a physics degree." She had a narrow idea of her career path, and though she now sees more options, she feels unprepared to pursue them. Some who now work in finance, tourism, or shipping wish they could have learned earlier about the wide variety of opportunities open to them.

Several participants reported that hiring managers in non-physics industries were unaware of the skills inherent in a physics major that could apply to many jobs. One who applied to work for a shipping supplier said, "When I told people I was a physics major their jaws dropped." Another said that he met the qualifications for many engineering positions, but didn't get hiring managers' attention because his résumé identified him as a physicist rather than an engineer. Another participant reported that the career prospects for physics majors are obscure not only for hiring managers, but also for families: when he told his parents he was majoring in physics, he said, "They were silent. They didn't see the acceptance of physics in the real world, which to them is business."

Participants had various suggestions about how the marketability of a degree in physics might be better communicated. One wishes that the guest lectures she attended in her first year could have been held later, when she was job-hunting and wanted more perspective about career opportunities. Another suggested that entrepreneurial programs such as the one he attended "give physics majors a chance to apply their knowledge and open up the universe of things for them to do." The same participant suggested, "With a physics degree you can kind of do anything, so what about taking some extra finance classes to supplement your physics degree?"

The culture of physics discriminates against certain learners

Some participants said that they wish they had learned earlier that many different kinds of people can succeed and thrive in a physics degree program. They reported getting messages that physics is only appropriate for certain people, and wished they had had the perspective to discount these messages. For example, one participant reported that his peers were needlessly driven away from physics by an influential physics professor who promoted an innate intelligence model with statements like "If you're smart, you will be able to do this," those who had to exert effort felt that they weren't smart and didn't belong. This same participant obtained a minor in art history, and observed that the more generous grading in his minor discipline made students feel that they were "better at art history" even though they could have been excellent physicists. Another participant pointed out that physics instruction rewards students who match equations with variables in the textbook and discriminates against students with more intuitive or conceptual approaches to problem-solving, even though those latter students could make the best scientists in the long run. These students wish they had learned earlier that a good physics major is one who either has, or can acquire, the skills and dispositions of physicists, and that physics culture excludes some people for the wrong reasons.

Other

One participant wishes he had done more Fermi-type estimation problems in his degree program; he "does that a million times a day now," and perceives it as "very important in industry applications." Another wishes that she had known about the geographical implications of her subject area, saying, "They don't tell you that all the space jobs are in Texas, Florida, and Alabama." Some participants wish they could have learned about business in their degree program, feeling that their lack of exposure to the basics of entrepreneurship had limited their career opportunities. One participant who felt that his degree program had perfectly launched his career had participated in an "Entrepreneurial studies in the sciences" program that taught him such diverse skills as résumé writing, what an LLC is, how to sell an idea, and the different communication styles required for the front desk, a middle manager, and an executive; he perceives this preparation as rare, and wishes more physics majors could experience it.

Interviews with Hiring Managers

Hiring managers were interviewed according to the protocol below (with variants depending on whether the hiring manager was referred by an employee or identified some other way):

1. What qualities or skills did [employee name] have that led you to hire him/her? Were these qualities related to his/her degree in physics? How did you know to hire a person with a physics degree, or was that not a part of your decision process? [OR] What qualities or skills do physics majors have that makes you want to hire them?
2. What qualities or skills would make such individuals more valuable or easier to hire?
3. If you could give advice to physics departments that prepare your employees, what advice would that be?
4. If you could give advice to physics students looking for employment in your area, what advice would that be?
5. Is there anything you want to add, or any questions you want to ask me?

Because there were only five hiring managers interviewed, responses to each question are organized by what each hiring manager said (rather than by responses that arose frequently, as in the previous section). The hiring managers' pseudonyms are as follows:

"Anne" hires for an electronic health records software company.
"Brian" hires for a federally funded research and development center.
"Chris" hires for a company that does custom technical design and development.
"Doug" hires for an experimental lab.
"Ella" hires for a petrochemical testing facility.

Not every hiring manager responded substantively to every question. For example, Ella does not associate her employee's desirable qualities with his background in physics, so some of the questions were not relevant to her.

What desirable qualities or skills do hiring managers perceive physics majors as having?

Physics is Anne's top choice of major for hiring; she said, "I get really excited when I see a physics major." She perceives physics majors as being very technical, experienced with coding, strong problem solvers, comfortable with computer modeling and simulation, and fluent with math. She also sees them as having a lot of variety in their personalities: some are very well spoken and can communicate with customers (unlike computer science majors, whom she perceives as rarely able to work with customers).

Brian values physics majors for their attitude about equipment, saying, "The instinct that a physics major has is, "Yes, I'm going to use this equipment but I need to know what it does so that I can modify it or use it off-label." He values physics majors who like working with their hands, and has little use for those whose success was primarily in homework and exams.

Chris values physics majors primarily for their broad training, which prepares them to be trained in the specific practices relevant to his company. Electrical engineers are overspecialized for his purposes. Chris also perceives physics majors as interfacing well with scientists and being prepared to solve difficult problems independently. He values hirees with technical training and takes interns from a nearby university to develop their technical competence.

Doug values physics majors because he perceives that "physics majors tend to be point-and-shoot," meaning that "they can solve problems with a minimal amount of input."

Ella hired the referring physics major for his work ethic and his experience in the military rather than for skills she associates with his degree in physics.

What qualities or skills would make physics majors more valuable or appealing to hiring managers?

Anne perceives no important weaknesses in physics majors as a group. They are her first choice of hirees; she only wishes she had more of them applying to her company.

Brian would more highly value physics majors with more research experience, more experience working effectively on a team, and more preparation in scientific communication, especially writing. He wants more people who can see the big picture, troubleshoot equipment, and problem-solve independently, and perceives this skill as developing when physics majors work in an experimental research lab (not when they take a lab class). He wants more people who can interact effectively with a diverse group of scientists, who can assemble a team from different areas and push back on their supervisor when necessary. He also wants physics majors to have better communication skills (writing and oral presentation) in order to communicate effectively with non-scientist stakeholders in government and the military. Finally, physics majors tend to be too perfectionist, in his opinion; he needs people who have practice getting a job done well enough on time.

Chris perceives that physics majors do not necessarily have strong "people skills." The physics majors that are valuable to him are "very bright people who can work well on a team, not just do problems on paper." His business depends on his employees communicating with their partners effectively both orally and in writing. He values collaboration and consensus above defensive argumentation; he wants employees that are "argumentative, but also understand that they are working with people."

Doug is more eager to hire physics majors with summer research experience, and supports research internships for physics majors from a nearby university partly to recruit them into his lab. In his perception, physics majors who get this experience work exceedingly well alongside scientists with PhDs; he says "they just jump right into the job," partly because their classwork is fresh in their minds. Some of their most highly-ranked employees are those with bachelor's degrees in physics; he says, "They do all the real work, and the PhD physicists sit around and think high thoughts." Doug also wants physics majors to get more experience with MatLab and Mathematica, because his lab relies on them for analysis.

What would hiring managers advise physics departments to do to prepare physics majors for employment in their area?

Anne would advise physics departments to help companies like hers connect with physics majors, saying, "They have been our hidden gem." She perceives physics departments as lacking the strong communities, placement infrastructure, and career centers that many engineering programs have, and would like more routes through which to recruit physics majors. She would also advise physics departments to help physics majors understand that "they come with a lot of highly valuable skills that they might not necessarily recognize" as relevant to companies like hers, including being "strong problem solvers with a lot of technical experience."

Brian would advise physics departments to support students in getting involved with a research group as quickly as possible. He perceives physics classes as being primarily about the history of physics, rather than the doing of physics. Brian would also advise physics departments to support introspection for students on their internal reward system – to ask themselves, "What's going to make me happy doing a job?" He wishes departments would help students think beyond academia, to consider careers with more tangible impact. He would also advise departments to promote teaching opportunities (such as learning assistantships or tutoring), and make physics majors aware that teaching skills are valuable in many careers.

Chris would also advise departments to make internships available to physics majors, perhaps by collaborating with industry partners. His company has a working relationship with a physics lab at a nearby university; he is adjunct faculty there, and offers partial support for internships at his company (with the balance coming from federal funding). He would advise physics departments to cultivate such programs to showcase their physics majors, provide them with excellent career opportunities, and provide companies like his with better employees.

Doug, who already has a thriving university partnership that provides him with physics major interns, would advise physics departments to support physics majors in effective scientific communication, especially writing and presenting orally to a group. He said, "I don't want to hire an egghead, someone who sits in his office and doesn't want to come out." Mathematical skills tend to be more equal among physics majors; he finds it easier to hire physics majors who can communicate complex ideas in a simple way.

What would hiring managers advise physics majors to do to prepare for employment in their area?

Brian would advise physics majors to get involved in a research lab, to take advantage of teaching opportunities, and to go to the departmental colloquium to learn about fields that are not addressed in standard courses. In his work, he uses what he learned in every single undergraduate and graduate physics course that he ever took. He would advise physics majors to recognize that physics is not a series of independent towers of courses, but is all one whole; this knowledge will strongly benefit them as future employees, because most of the problems they will face will be multidisciplinary. For example, he once worked on a communications satellite carrying atomic clocks; the clocks were not functioning properly, and a team of materials scientists, atomic physicists, thermal engineers, and scientists from other disciplines had to work together to identify the problem.

Chris would advise physics majors to take advantage of internships if available, in order to learn about physics jobs beyond academia and national labs. He would advise them to obtain a well-rounded education that includes communication and problem solving as well as physics.

Doug would advise physics majors to take courses in English composition. He says that everyone he sees has the same physics courses; the ones who stand out are the ones who can write.

Relationship of Physics Major Perceptions to Hiring Manager Perceptions

This study reports which skills physics graduates perceive to have been beneficial to them in getting their current jobs; what they wish they had learned that would have improved their current jobs or their career trajectories; which skills hiring managers perceive physics majors to have; and which skills hiring managers wish physics majors had in better supply. The table below summarizes overall responses to these questions. (Blank cells in the table mean that that skill was not mentioned strongly in that category.) These results suggest that:

- Former physics majors and hiring managers agree that **disciplinary expertise** and **problem solving** are key strengths that seem to already be supported in physics degree programs.
- **Research and industry experience** is highly valued by hiring managers and desired by physics majors, along with experience in **programming**, and is perceived as lacking in some physics degree programs.
- Former physics majors and hiring managers agree that physics majors could benefit from a better understanding of the **marketability** of their degree.
- Some physics majors perceive **teaching** to have been a valuable part of their degree program, and some hiring managers would advise physics majors to get more teaching experience.
- Hiring managers strongly value **teamwork** and **communication skills**, but physics majors may not be aware of the value these have to hiring managers.

Skill	Do physics majors perceive that they use it?	Do physics majors wish they had more of it?	Do hiring managers perceive physics majors to have it?	Do hiring managers wish physics majors had it?
Physics	Yes		Yes	
Problem solving	Yes		Yes	Yes
Research/industry experience	Somewhat	Yes	Yes	Yes
Programming	Somewhat	Yes	Somewhat	Yes
Understand marketability		Yes		Yes
Teaching	Somewhat			Somewhat
Teamwork	Somewhat		Somewhat	Yes
Communication skills			Somewhat	Yes
Understand physics culture		Yes		

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