Preparing physics students for 21st-CENTURY CAREERS

Laurie McNeil and Paula Heron

Whether they end up in industrial, governmental, business, or academic settings, college graduates need plenty of skills beyond an ability to solve problem sets.

If you are a physics professor, you probably followed the traditional path to get where you are: undergraduate and graduate degrees in physics, one or more postdoctoral positions, and then a faculty position. Perhaps you think most of the physics majors you now teach will follow in your footsteps and that you best serve them by preparing them to become physics professors. If so, you are mistaken.

According to data from the Statistical Research Center of the American Institute of Physics (AIP; publisher of PHYSICS TODAY), only about 3% of US physics bachelor’s degree graduates end up employed as physics professors—though others may pursue academic careers in related fields, such as engineering or computer science. The vast majority of physics bachelor’s degree recipients are employed outside academia for at least part, and often all, of their careers and are engaged in various jobs, about half of which are in the private sector. (Figure 1 illustrates the data on recent graduates’ initial employment.)

Few physics programs are explicitly designed to prepare students for that likely career outcome. Both physics graduates and their employers report that graduates should be better prepared for positions requiring scientific training, that observation is equally applicable for physics PhD holders (see PHYSICS TODAY, June 1995, page 13). Almost half of them hold positions outside academia one year after receiving their degrees, and most of them move to private-sector or government positions after completing a position. When surveyed, physics graduates working in the private sector report that they regularly need to use skills beyond their knowledge of physics; figure 2 presents the data. Working in teams, technical writing, programming, applying physics to interdisciplinary problems, designing and developing products, and managing complex projects are all acquired skills. But for most physicists, developing them was only a small part of their educational experience.

In 2014 the American Physical Society (APS) and the American Association of Physics Teachers (AAPT) convened a joint
### 21st-CENTURY CAREERS

<table>
<thead>
<tr>
<th>Field of employment for physics bachelors in the private sector</th>
<th>Other STEM 32%</th>
<th>Engineering 36%</th>
<th>Computer or information systems 12%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical or astronomy 8%</td>
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<td>Non-STEM 24%</td>
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<tr>
<td>Civilian government (including national labs) 5%</td>
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<td>Active military</td>
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<tr>
<td>Obs. 6%</td>
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<tr>
<td>High school 18%</td>
<td></td>
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<tr>
<td>College and university</td>
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#### Initial employment sectors of physics bachelors

**Figure 1. The Private Sector** employs 65% of physics bachelors who entered the workforce after receiving their degrees, according to a survey of graduates from 2013 and 2014. (This chart does not include the 54% of all degree recipients who entered graduate school immediately.) College and university employment refers primarily to staff, not faculty, positions. "Other" employment includes elementary and middle schools, hospitals and other medical facilities, and nonprofit organizations. In the private sector, the graduates are primarily employed in STEM (science, technology, engineering, and mathematics) jobs, though a significant fraction are employed in non-STEM fields such as finance and the service industry. (Adapted from ref. 4)

#### What do physics graduates need?

We concluded that physics graduates are generally already prepared to pursue many careers and are sought for their flexible problem-solving skills, and exposure to a range of technologies. But most would benefit from a wider and deeper knowledge of computational-analysis tools, particularly industry-standard packages; broad set of experiences, such as internships and applied research projects, that engage them with industrial work; and a closer connection among physics content, applications, and innovation. Graduates would also be more successful in the workplace if their undergraduate physics program included basic business concepts and professional skills such as teamwork and effective communication.

Faculty members have traditionally focused on ensuring that students master the fundamental physics concepts of the core curriculum—mechanics, electricity and magnetism, thermodynamics and statistical mechanics, quantum mechanics—and their application in areas such as optics, nuclear physics, and condensed-matter physics. Students also gain skills in numerical, analytical, and experimental methods while studying those subjects. It is less common, however, for them to pick up skills associated with applying fundamental physics in interdisciplinary contexts and in the wide variety of nonacademic career settings they are likely to encounter.

#### What can physics programs do?

The large list of skills and knowledge that physics graduates need may seem daunting to both students and faculty members. How can a program provide a student with all that career preparation and yet still make sure she can solve Schrödinger's equation? Fortunately, most of the skills can be pursued through more than one channel. Depending on such factors as an institution's human and financial resources, the size and aspirations of its student body, and the existence of local industries, physics departments can choose different strategies. They may redesign their programs entirely, infuse skill development into already existing courses, or build the skills primarily with curricular activities. In the J-PURP report, we provide many examples of approaches that have been adopted by physics departments. (For an earlier account of approaches and innovations made by departments to prepare their students for various job opportunities, see the article by Barrett Ripin, PHYSICS TODAY, April 2001, page 53.)

Most faculty members will think that their standard courses already provide a foundation in physics knowledge and, rightly so. But why stop there? The content of virtually any program can be used to provide a broader range of skills useful in a variety of contexts. (Adapted from ref. 4)

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1. We consulted several resources to answer these questions. To develop a clear picture of what, ideally, a physics graduate should know to be successful in a wide range of careers, we studied the findings of other academic societies, education associations, and business and government groups; conducted interviews with, among others, physicists in nonacademic careers and developers of innovative university programs; and commissioned a study of physics graduates and their employers. We also drew heavily from previous work, such as the Care Pathways Project report prepared by AIP's Statistical Research Center and the Society of Physics Students and commissioned a set of case studies of departments that had modified their programs to enhance graduates' career readiness in order to find examples of strategies that other departments could adopt.

2. The report on the reorganization of the curriculum and the recent curricular reforms in the Department of Physics at the University of California, Berkeley, demonstrates the need for these changes.

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**Knowledge and skills regularly used by physics bachelors**

<table>
<thead>
<tr>
<th>Knowledge and skills regularly used by physics bachelors</th>
<th>Engineering</th>
<th>Computer science or information technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solve technical problems</td>
<td>Work on a team</td>
<td>Perform quality control</td>
</tr>
<tr>
<td>Work on a team</td>
<td>Use specialized equipment</td>
<td>Manage projects</td>
</tr>
<tr>
<td>Perform quality control</td>
<td>Manage projects</td>
<td>Knowledge of physics or astronomy</td>
</tr>
<tr>
<td>Use specialized equipment</td>
<td>Manage projects</td>
<td>Design and development</td>
</tr>
<tr>
<td>Manage projects</td>
<td>Manage projects</td>
<td>Programming</td>
</tr>
<tr>
<td>Manage projects</td>
<td>Manage projects</td>
<td>Work with customers</td>
</tr>
<tr>
<td>Advanced math</td>
<td>Manage projects</td>
<td>Manage projects</td>
</tr>
<tr>
<td>Scientific writing</td>
<td>Manage projects</td>
<td>Manage budgets</td>
</tr>
<tr>
<td>Management</td>
<td>Manage budgets</td>
<td>Manage budgets</td>
</tr>
</tbody>
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**Figure 2. When polled about what kinds of knowledge and skills they rely on daily, weekly, or monthly, physics graduates from 2013 and 2014 now working at private sector jobs in engineering or computer science said that in both the broad field of physics and in other areas of research, they need to teach a complex idea or method to others, evaluate how well it was absorbed, and develop a strategy to more effectively communicate the idea. But most physics programs include no specific opportunities to develop such skills, even for students who coauthor scientific publications and present their research at professional conferences.**

Most physics programs also shortchange their students in another way: They rarely help them learn about career opportunities in physics, how to find a job, or how to assess the relevance and importance of their skill set to that job. That many physics faculty members are only vaguely aware of careers outside academia makes their students' transition to the workforce doubly challenging.
21st-CENTURY CAREERS

Middle school science teacher
Mechanical engineer
Web developer
Field engineer
Accelerator operator

High school physics teacher
Electrical engineer
Software engineer

Process engineer
Physical sciences technician
Manufacturing engineer
Programmer
Research technician
Research engineer

Such as career services or industrial relations, and with employees off campus to create immersive internships or intensive interdisciplinary programs on topics such as innovation and entrepreneurship. Such collaborations are brilliant for students to pursue multiple learning goals in one program. Used in engineering schools for decades, internships allow students to spend time off campus. In addition to giving direct exposure to product development and manufacturing, internships can help students focus on nontechnical aspects of science, such as documentation and business development. Students placed at science service companies are exposed to proposal preparation, project cost tracking, corporate structures, and project execution. Technology transfer officers at national laboratories often advise college students to learn about patents, licensing, and commercialization.

Internships often lead to job opportunities, and students interested in a particular industry would do well to intern with a leading firm in that industry. In designing such 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. For students with an interest in big data, some institutions offer boot camps that provide students with hands-on experience and assistance landing jobs in that specialty (see PHYSICS TODAY, August 2016, page 20).

A physics degree that does not implement significant changes in its program may nevertheless benefit students by making its curriculum flexible enough to be tailored to specific career paths. Some students, for example, could replace a few traditional core courses with electives of industrial relevance, such as condensed-matter physics and optics. Others might opt for electives from engineering, biology, statistics, computer science, speech, business, technical, and creative writing, or even philosophy. The substitutions can be made on a student-by-student basis or organized into predetermined tracks of recommended electives. Alternatively, new courses can be designed around specific applications that involve important physics concepts. A course focused on solar cells, for instance, could encompass quantum mechanics, thermal physics, solid-state physics, and more. And a course designed around the challenges and solutions associated with clean energy, clean water, and the environment could offer a broad perspective on the use of physics to solve societal problems.

Another program modification that can enhance students' career preparation is to capstone a variety: a thesis, senior seminar, or some other relevant experience. Often students will insert a research laboratory, conduct research on a historical scientific breakthrough, or carry out an experiment of their own under faculty guidance—and write up the work in each case. This activity can be tailored to address one or more of the learning goals we have mentioned in this article or in some cases can even incorporate industry-standard skills—commercial simulation or graphics packages, say, or computer-aided design—as part of the project.

What's in it for the department?

Even the minor changes that are made to enhance graduates' career preparation require sustained effort by faculty members. What would be the reward for you and your department? First, you will be able to attract and retain the most talented and diverse group of students who might otherwise have chosen different disciplines or other institutions. Second, enhancing your students' engagement with applied research is likely to lead to new, interesting research questions. Finally, those relatively few students who do graduate school will have developed skills that are useful in a research group as they are in the workforce.

Ultimately, we believe that you and your department should follow your recommendations because you desire two things. One is to prepare 21st-century graduates as effectively as possible for the diverse careers they can be expected to have. The other is that your department does not become irrelevant. If you will follow up by providing support for students to pursue their interests and skillsets, we are confident that the discipline of physics will continue to be robust and vibrant through this century and beyond.

REFERENCES


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