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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 5% 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 more of them move to private-sector or government positions after completing a postdoc. 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

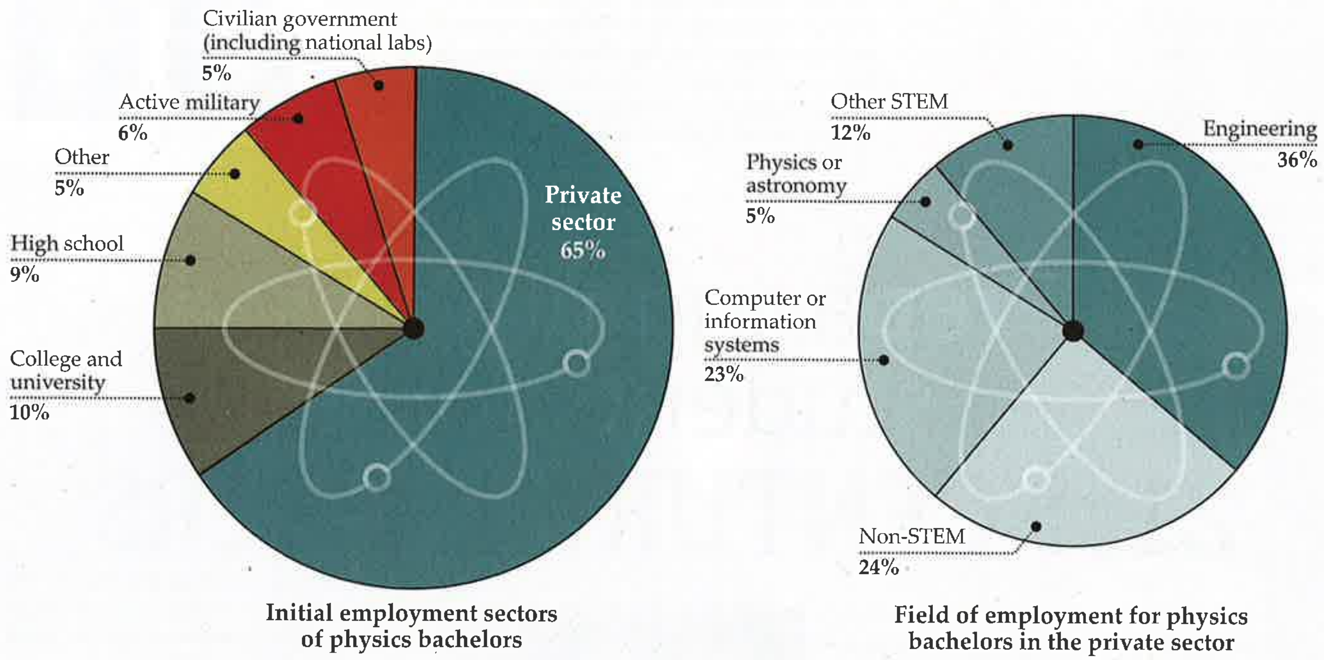

FIGURE 1. THE PRIVATE SECTOR employs 65% of physics bachelors who entered the workforce after receiving their degrees, according to a survey of graduates from 2013 and 2014. (This chart does not include the 54% of all degree recipients who entered graduate school immediately.) College and university 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.)

task force on undergraduate physics programs (J-TUPP) to address that shortcoming. We and our colleagues on J-TUPP, whose members were drawn from the academic and industrial-physics communities, were asked two broad questions: What skills and knowledge should the next generation of undergraduate physics degree holders possess to be well prepared for a diverse set of careers? And how might physics departments revise their undergraduate programs to help students? Our report is now available.[1]

We consulted several resources to answer those 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 Career Pathways Project report prepared by AIP's Statistical Research Center and the Society of Physics Students,[2] and commissioned a set of case studies of departments that have modified their programs to enhance graduates' career readiness in order to find examples of strategies that other departments could adopt.

What do physics graduates need?

We concluded that physics graduates are generally already prepared to pursue many careers and are sought for their flexibility, 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; a broader 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.

Faculty members can serve their students well by providing opportunities to acquire scientific and technical skills not necessarily specific to physics—for example, problem solving beyond the typical problem sets needed to master basic concepts; generic experimental skills in optics, vacuum technology, and electronics; coding and software use; data processing, acquisition, and analysis; and troubleshooting, calibrating, and repairing equipment. Some aspects of those skills are components of traditional coursework and advanced laboratories. However, without an explicit goal of inculcating such skills and developing specific activities to achieve it, some students may fall through the cracks. Perhaps equally problematic, they may fail to recognize the marketable skills they actually have acquired and which employment opportunities suit them best. Interestingly, in the list of common job titles given in figure 3, only one—high school physics teacher—includes the word physics.

When a physics graduate enters the workplace (or, for that matter, undertakes a dissertation project), she is likely to face the challenge of solving complex, ambiguous problems in real-world contexts. She will need to define and formulate specific questions, perform literature searches, and understand what she discovers well enough to develop a strategy for answering her questions—whether by conducting experiments, performing a simulation, making an analytical model, or taking countless other approaches. To implement the strategy, she will need to identify resource needs and make decisions or recommendations for beginning or continuing a project, determine the appropriate next steps, and place the results in a broad perspective. It is likely she will have had little experience doing such tasks unless her undergraduate program offered the opportunity to develop the needed skills.

Competency in instrumentation, software, computation, and data analysis is vital to success in key parts of the workplace or dissertation challenge. A recent report by the AAPT Undergraduate Curriculum Task Force contains useful recommendations for incorporating computational physics into undergraduate programs.[3] Computational software packages are widely used in the private sector, and many are available in an educational version at little or no cost. Although the student versions may lack some functions found in full-price ones, they suffice as an introduction. The graduates we interviewed were virtually unanimous in their desire for more programming skills. Competency in analyzing data, distinguishing between models, and presenting results is important in many careers pursued by physics graduates. The omission of that type of preparation from their college programs puts graduates at a disadvantage compared with their engineering-major peers, who are more likely to have had such experience.

Members of the broader physics community are well aware of graduates' need for good communication skills. But too often a physics program focuses primarily on the preparation of refereed publications. A physicist in an industrial or government setting is likely to need the ability to make her ideas and results accessible to people untrained in science, including managers, sponsors, members of Congress, marketing personnel, technicians, and members of the public. The graduate will also need to articulate her understanding and be persuasive in communicating the worth of her and others' ideas using words, equations, tables, diagrams, pictures, animations, and other visualization tools. Or she may 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 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.

What can physics programs do?

The long 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 cocurricular activities. In the J-TUPP report, we provide many examples of approaches that have been adopted by physics departments.[1] (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 43.)

Most faculty members will think that their standard courses already provide a firm foundation of physics knowledge, and rightly so. But why stop there? The content of virtually any

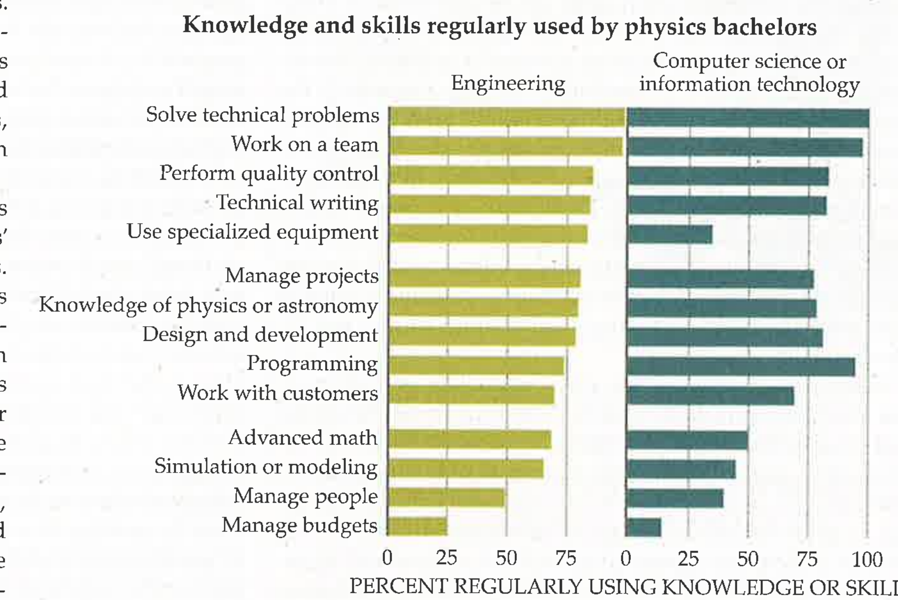

FIGURE 2. WHEN POLLED ABOUT WHAT KINDS OF KNOWLEDGE AND SKILLS they rely on daily, weekly, or monthly, physics graduates from 2013 and 2014 now working at private-sector jobs in engineering or computer science cited the broad range listed here. Graduates in both fields ranked several technical and professional skills as more useful—or more precisely, used more regularly—than a knowledge of physics. (Adapted from ref. 4.)

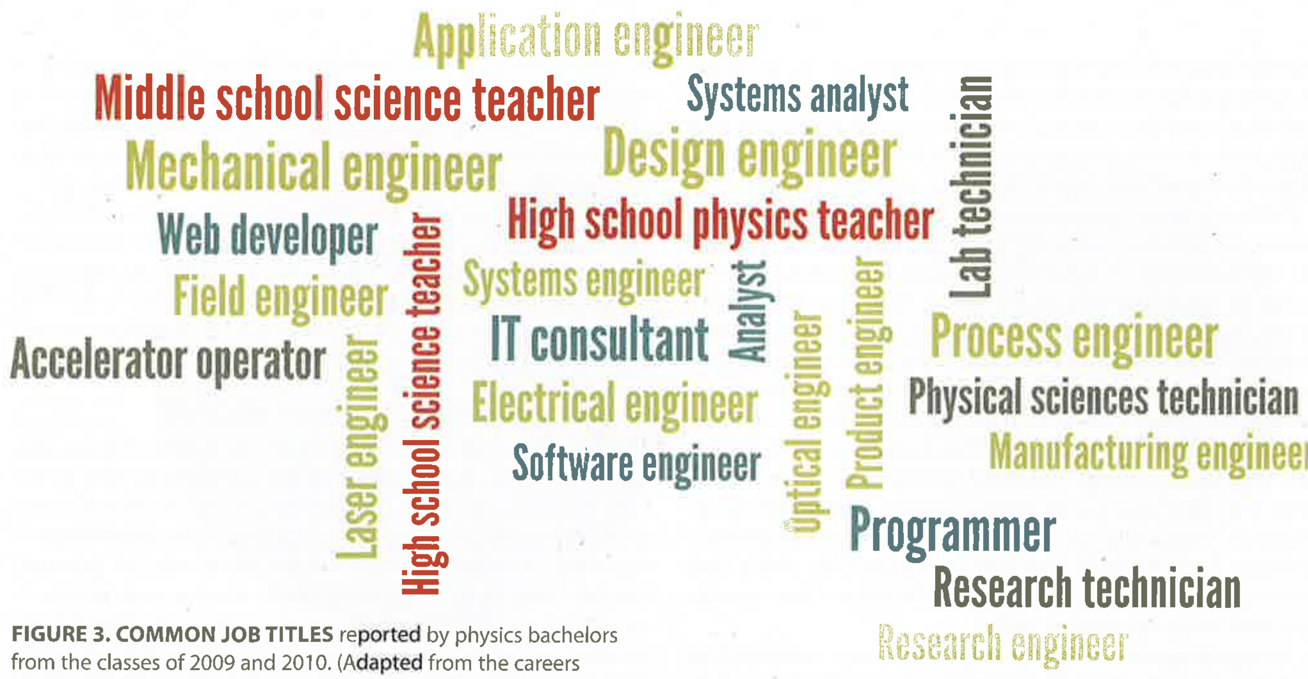

FIGURE 3. COMMON JOB TITLES reported by physics bachelors from the classes of 2009 and 2010. (Adapted from the careers toolbox for undergraduate physics students, AIP Career Pathways Project, www.spsnational.org/careerstoolbox.)

physics course can be related to career-relevant applications while maintaining a focus on fundamentals. Even general relativity finds a practical use—in GPS technology. Physical principles can be applied to industrial processes or commercial devices, say, without sacrificing an appreciation of the core fundamentals. As mentioned earlier, commercial products can also be incorporated into laboratory courses to familiarize students with industry-standard software packages.

Students' communication skills can be addressed at many points in a curriculum. For example, students may produce oral reports on topics relevant to a course or as part of a seminar. Or they may give presentations on their research to the public—perhaps as part of outreach efforts. And not all skill development needs to take place in the physics department. Writing and editing skills can be cultivated in English or communications departments. Basic business concepts can be learned through courses taught in engineering departments or in business schools. Career-placement offices on campus can partner with physics departments to help students conduct a successful job search by honing their resumé-writing and interview skills.

Cocurricular activities are often overlooked as opportunities to develop professional skills. Departments can host talks and other events that feature physics graduates in diverse careers. They can support student organizations in industrial site visits and educational outreach activities. And they can encourage students to take advantage of development activities offered at conferences sponsored by national professional organizations such as the AIP member societies. Formal opportunities to teach or tutor others are yet another way to help students without expanding the physics major.

Collaborations and a flexible curriculum

A department that is prepared to make significant changes can collaborate with other departments and offices on campus, such as career services or industrial relations, and with employers off campus to create immersive internships or intensive interdisciplinary programs on themes such as innovation and entrepreneurship. (See the article by Douglas Arion, PHYSICS TODAY, August 2013, page 42.) Such collaborations are brilliant ways for students to pursue multiple learning goals in a single coherent program. Used in engineering schools for decades, internships allow students to spend time in an off-campus workplace. 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 scientific service companies are exposed to proposal preparation, project cost tracking, corporate structures, and project execution. Technology-transfer offices at national laboratories can allow 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 department that chooses not to 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 a capstone activity: a thesis, senior seminar, or some other relevant experience. Often students will intern in 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. The activities 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 most minor changes that are made to enhance graduates' career preparedness require sustained effort by faculty members. What would be the reward for you and your department? First, if you investigate the employment outcomes of your program's recent graduates and the career aspirations and prospects of your current and future students, you will better know your students and be able to help them achieve their full potential after graduation. Second, adopting career-preparedness strategies will enhance your department's reputation and attract a talented and diverse group of students who might otherwise have chosen different disciplines or other institutions. Third, enhancing your students' engagement with applied research is likely to lead to new, interesting research questions. Finally, those relatively few students who go to graduate school will have developed skills that are as useful in a research group as they are in the workforce.

Ultimately, we believe that you and your department should follow our 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 obtain the many benefits that will follow from fulfilling the first desire—in other words, to pursue enlightened self-interest. If enough of you choose to follow the suggestions, we are confident that the discipline of physics will continue in robust health through this century and beyond.

REFERENCES

1. Joint Task Force on Undergraduate Physics Programs, *Phys 21: Preparing Physics Students for 21st-Century Careers*, American Physical Society (October 2016).
2. R. Czujko, K. Redmond, T. Sauncy, T. Olsen, *Equipping Physics Majors for the STEM Workforce*, American Institute of Physics Career Pathways Project (December 2014). See also Society of Physics Students, "AIP Career Pathways Project," www.spsnational.org/career-resources/career-pathways.
3. AAPT Undergraduate Curriculum Task Force, *AAPT Recommendations for Computational Physics in the Undergraduate Physics Curriculum*, American Association of Physics Teachers (October 2016).
4. P. Mulvey, J. Pold, *Physics Bachelors: Initial Employment*, American Institute of Physics Statistical Research Center (April 2017). PT