

IS PHYSICS EDUCATION ADAPTING TO A CHANGING WORLD?

A survey of educators finds little evidence that physics training is broadening in response to current shortages of jobs and research funds.

Werner P. Wolf

The future of education, research and employment in physics has been under much discussion lately. Contrary to many glowing predictions in the mid-1980s, physicists graduating today face a severe shortage of jobs. Recalling comments such as one made by Malcolm Beasley and Lawrence Jones (PHYSICS TODAY, June 1986, page 36) that "It appears that the overall demand will more and more exceed the supply in the coming decade" reminds us just how much the situation has changed. Many solutions are being proposed. Articles relating to jobs and offering employment advice proliferate in the publications of our scientific societies. The situation is similar in other countries.

Part of the problem is due to recent changes in defense spending and in the economy. But over the longer term the problem is more systemic. As John Rowell pointed out two years ago (PHYSICS TODAY, May 1992, page 40), science is subject to the same laws of supply and demand as other commodities, and continued growth is simply not sustainable.

One solution would be to limit the number of students. This would surely be anathema to many established physicists, who believe that training in physics is and will always be a valuable education. This approach also suffers from the drawback that, as experience has shown, it is very difficult to predict future job opportunities.

Another approach, advocated recently by Sheila Tobias, would be for physics educators to "use the model of the law schools to figure out how to increase the size and diversity of demand for their graduates."¹ Implicit in this approach is the idea that "the training of physicists must become less specialized, less reductionist, if they are to be prepared to face the real world in a wide variety of complex areas." Such ideas are not new. Some of us have been

advocating a change in attitude for many years now,² but the strong employment market made it unnecessary to give widespread thought to making changes.

Now that Washington is giving clear signals that funding will become increasingly directed toward more "strategic" research, and now that students can no longer rely on their thesis advisers to get them a job, it has become urgent to review the state of physics education in the United States and to consider changes that might make a training in physics or applied physics more broadly useful.

To obtain further insight into the subject, I surveyed 90 colleges and universities by mail and held telephone conversations with some two dozen colleagues in various institutions. About half the surveys were sent to a group of high-quality four-year undergraduate colleges. The remainder of the surveys were split between universities that the National Academy of Sciences listed in the top 20 in its 1982 ranking of graduate physics programs and a group of 20 PhD-granting universities that the AIP listed as having applied or engineering physics undergraduate programs. Sixty-nine percent of the colleges and 52% of the universities responded.

Undergraduate programs

Some questions concerning undergraduate programs aimed to find out what kinds of courses students typically took and whether there were significant moves to shift the curriculum toward a more "applied" emphasis. Some questions explored opportunities for students to gain research experience outside the regular physics department. For institutions that offered an applied physics or engineering physics option, questions examined how these programs differed from regular physics degree programs. Another set of questions asked where the students went after their undergraduate degrees and, specifically, how many chose careers outside regular physics.

Many of the responses were quite extensive, and it is

Werner Wolf is Raymond J. Wean Professor and chairman of the department of applied physics at Yale University, in New Haven, Connecticut.



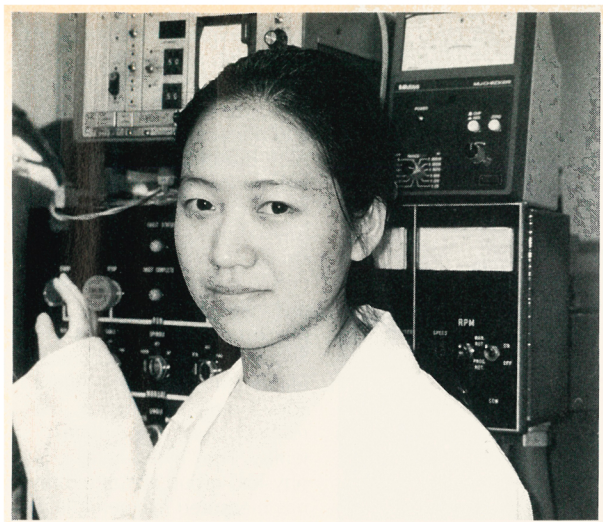
Interdisciplinary research. At Vanderbilt University in Nashville, Tennessee, physics professor John Wikswo (top) and physics graduate student Alan Bradshaw transfer liquid helium into a general purpose SQUID magnetometer, which is housed inside a magnetic shield. In the background are (left to right) physics research associate Daniel Staton, physics graduate student Sergei Rousakov, mechanical engineering graduate student Tony Ewing and physics research associate William Jenks. The "living-state physics" group at Vanderbilt has measured magnetic fields from objects as diverse as human nerves and intestinal smooth muscle, parasites in fish, thin sections of rock, containers of water, samples of Plexiglas, nuclear reactor fuel tubes and sections of aircraft wings. (Photograph by John McDonough; courtesy of Wikswo.)

clear that there is a considerable amount of interest in questions such as these. It is impossible to give a complete account of all the data collected and the many excellent comments that were made, but I will try to highlight the principal conclusions.

Undergraduate curriculum. Table 1 shows the courses taken by undergraduate physics majors at four-year colleges. There is clearly a consensus on the most widely taken courses. What may be surprising are the courses *not* taken by large numbers of students. Courses taken by very few students include computer interfacing (3%), biophysics (2%) and fluids (1%). Some respondents commented that this is due partially to the fact that undergraduates can take only a limited number of science

courses and still fulfill their other requirements. Also, small enrollments make offering more specialized courses difficult for departments to justify. Collaborations between nearby colleges may be a partial answer to that problem.

A number of the colleges surveyed do offer courses in topics that may be described as "applied" in some sense, but generally such courses are rare. The main exception was electronics, which is offered by 41% of the colleges and taken by 29% of all physics majors. In an attempt to broaden the curriculum, a few physics departments have devised concentrations in such fields as computer science or biophysics *within* the physics major, but there was little evidence that others were planning similar



Summer intern. The Industrial Summer Intern Program, organized by the American Physical Society but fully supported by industry, has been providing undergraduates with applied research experience since 1979. Purdue University physics major Jiamian Chen is shown here as a 1994 summer intern at Advanced Technology Materials Inc., in Danbury, Connecticut. Chen worked on the preparation and optical characterization of silicon carbide substrates for use in semiconductor electronics. (Courtesy of Phyllis Banucci, ATMI.)

innovations.

Seven of the colleges reported that they offer "3-2" programs, in which students move to an engineering school after three years of undergraduate physics.

At universities that have an engineering school on campus, a variety of applied physics or engineering physics programs are possible. It was surprising to learn, therefore, that there are altogether only 27 engineering physics programs accredited by the Accreditation Board for Engineering and Technology in the United States. In my survey, details of engineering physics programs were supplied by the University of Kansas, the University of Michigan and Colorado State University (which also has an applied physics program). Details of applied physics programs were provided by the California Institute of Technology, the Colorado School of Mines, Cornell University, Georgia Institute of Technology, Purdue University and Yale University. Compared with regular physics degree programs all these programs seem to offer a considerable degree of flexibility, allowing students to explore a wide range of areas beyond the narrow definition of physics. At Purdue, for example, the applied physics program has 16 specialties: acoustics, atmospheric physics, coherent and quantum optics, environmental health physics, geophysics, health physics, medical physics, meteorology, nuclear energy, physical metallurgy, plasma physics, reactor health physics, scientific programming, small computers in research, solid-state device physics and spectroscopy.

The survey tried to explore the differences between majors in engineering or applied physics and regular physics, and the possibility of switching between them. As one might expect, engineering physics programs generally carry heavier course loads than do regular physics majors. One respondent described an engineering physics program as "more like a double major, because it covers advanced material in both physics and engineering." Applied physics programs tend not to be quite so intense. Switching between physics and one of the "applied" programs is easy if the other program is in the same school, but if, as is usual, the physics program is in the college of arts and sciences while the engineering physics program is in the engineering school, transferring may be more difficult.

All of this suggests that while engineering physics majors exist and are taken by a number of motivated students, such programs do not fulfill the needs of students

interested primarily in physics but looking for a more "applied" track within it. Applied physics majors *within* the same school as the physics major, or even applied physics tracks within the same department, would seem to offer a much more flexible alternative, but this appears to have been explored in only a few institutions.

Research and outreach. A number of respondents spoke with enthusiasm about the importance of undergraduate research involvement as a broadening experience, but a surprisingly large number—about 90%—indicated that this was not a *required* aspect of the training. (See table 1.)

Even though formal research *courses* may not be required, many respondents described a variety of mechanisms by which students could get experience outside the department. Of the 34 colleges responding, 21 mentioned summer research: ten at universities, nine at national labs, four in industry and two in medical schools. Seven mentioned the availability of research in other departments at their own institutions during the term; four described programs that allowed the student a whole term at a national lab; and one offered a similar program at a university. Mentioned as highly desirable were summer programs sponsored by the New England Consortium for Undergraduate Science Education, the Pew Charitable Trust, the American Physical Society and the National Science Foundation (specifically the Research Experience for Undergraduates program and the Research at Undergraduate Institutions program). Such activities can clearly be very enriching for the student, and one cannot help wondering whether this kind of opportunity could be made more widely available.

Comments on undergraduate programs. The majority of respondents felt that their present programs for undergraduates were quite successful and needed no significant changes. A number stressed the liberal arts aspect of college education and the fact that programs are already very full. Many seemed satisfied that their students had been successful with the training they had had in the past, and these respondents felt that physics majors compare very well with engineers.

David Nolte of Purdue University, commenting on the relative strengths of engineering and physics graduate students, made this interesting observation: "There is a perception that engineering will provide students with the skills to land a more promising job. This perception is definitely a danger to physics programs. On the other

1993 Job Titles of 1953–92 Haverford College Physics Graduates

The following list of recent job titles of Haverford College physics majors who graduated in 1953–92 shows a wider range of careers than would have been expected from the students' intentions at the time of graduation. While many of the graduates pursued careers related to physics in some evident way, a large number did not. Haverford physics professor Jerry Gollub assembled the list from a database provided by the college's alumni office. Similar profiles might be found for many other institutions with strong undergraduate physics programs.

Accounting and auditing

Bill collector
Partner

Architecture

Architect and builder
Senior vice president

Armed forces

Air Force physicist

Banking and finance

Economic adviser
Finance manager
Portfolio manager
Senior analyst
Vice president

Business: General

Manager—network systems

Communications: Printed media

Managing editor—magazine

Computers

Actuarial analyst
Director—academic computing
Director—engineering
Director—operations
Owner—computer business
Production manager
Project programmer analyst
Software engineer
Technical adviser
Technical consultant
Technical staff member
Vice president of development

Construction

Executive vice president
Electronics technician

Consulting

Assistant vice president
Department manager
Manager

Distribution: Retail and wholesale

President

Education: Primary and secondary

Program representative
Senior educator—science museum
Teacher—computers
Teacher—high school science
Teacher—religion
Teacher—mathematics
Teacher—math and science
Teacher—physics

Education: Higher

Assistant professor—astronomy
Assistant professor—imaging science

Associate professor—humanities

Lecturer—school health science

Professor—applied science

Professor—astrophysics

Professor—law

Professor—mathematics

Professor—mathematics

and computer science

Professor—philosophy

Professor—physics (7)

Research assistant—history

Engineering

Aerospace engineer
Chief scientist
Civil engineer
Engineer—university lab
Manager
Research and development
Sound engineer
Staff hydrologist

Entertainment

Gaffer—lighting director
Performing artist

Environment

Director of radiation safety

Government: Federal

Associate director, observatory

Government: Local

Police officer

Health care: General

Veterinarian

Insurance

Vice president and actuary

Law

Attorney—patent
Attorney—private practice

Manufacturing

Director of operations
Engineer
Manager

Medicine

Cardio and thoracic surgeon
Cardiology fellow
Family medicine—GP
Internist
Neurosurgeon
Orthopedic surgeon
Pathologist
Physicist—medical researcher
Pulmonary physician
Research scientist—immunology
Vascular surgeon

Nobel laureate

Physics 1993

Pharmaceutical

Research assistant

Physics

Air pollution control specialist
Artist—physicist
Astronomer
Astrophysicist—Smithsonian
Atmospheric physicist
Computational physicist
Educator
Manager—advanced systems
Medical physicist
Optical physicist
Project manager
R&D physicist
Radiological
Research—Naval Research Lab
Research reactor
Scientist—Plasma Fusion Center
Space scientist
Surface physicist
Systems analyst
Technical staff member
Vice president—protection apparatus

Publishing

Editor
President—periodicals

Religion

Researcher

Scientific research

Advanced silicon technology
Engineer at research center
Laboratory technician, genetics
Mechanical engineering
Molecular diagnostician
National laboratory scientist
Pharmaceutical labs
R&D—clinical products
X-ray microscopist

Students—PhD candidate

Astronomy
Atmospheric science
Computer science
Mechanical engineer
Medicine
Meteorology
Physics (13)
Religion

Writing

Technical writer

hand, most engineering professors prefer to have graduate students trained in physics. If physics departments could advertise this paradox to undergraduates—that physics majors make the best graduate engineers—then enrollment in physics could be significantly increased.”

Ned Rouze of Hope College summarized one problem

with the current situation: “I believe the main problem is one of exposure and encouragement. Most physicists are ‘pure’ physicists, and students see only this avenue. The training and background are not a problem. We need to increase the sensitivity and awareness of professors to career paths outside the classical path.”

Table 1. Courses taken by physics majors

Course	%	Course	%
Classical mechanics	95	Intermediate lab	6
Electromagnetism	95	Fields and waves	5
Quantum mechanics	88	Computer interfacing	3
Advanced lab	77	Independent projects	3
Statistical mechanics	68	Thermodynamics	3
Mathematical methods	59	Biophysics	2
Atomic physics	42	General relativity	1
Optics	38	Fluids	1
Nuclear and particle physics	29	Geophysics	1
Electronics	29	Microcomputers	1
Condensed matter	23	Advanced mechanics	1
Modern physics	18	Acoustics	1
Computational physics	14	Advanced modern physics	1
Astrophysics	10	Atmospheric physics	1
Senior thesis	10	Lasers	1
Theoretical physics	6	Nonlinear dynamics	1

Average percentages of physics majors in undergraduate colleges taking various courses. The total number of courses reported by 34 colleges was 326.

Table 2. Pure–applied ratings of research

Research area	Number of grad students	Pure–applied rating
Fluids and rheology	3	1.00
Astronomy and astrophysics	65	1.12
Relativity and gravitation	29	1.21
Particles and fields	197	1.23
Low-temperature physics	51	1.59
Nuclear physics	105	1.93
Computational physics	29	1.97
Statistical and thermal physics	45	2.31
Atmospheric and space physics	16	2.44
Biophysics	49	2.71
Polymers	17	2.82
Chemical physics	16	2.88
Condensed matter and solid state	500	2.95
Plasma physics and fusion	73	3.22
Atomic, molecular and optical	137	3.75
Other	35	3.97
Electromagnetism	41	4.02
Electronics	8	4.25
Surface science	61	4.31
Physics education	7	4.43
Geophysics	4	4.75
Acoustics	14	4.86
Medical and health physics	22	5.09
Materials science and metallurgy	91	5.29
Energy sources	11	6.00
Engineering and applied physics	69	6.61
Average pure–applied rating		3.02

Pure–applied ratings and numbers of graduate students currently involved for 26 research areas. Most pure = 1; most applied = 7. Data supplied by 24 universities for 1695 students.

The wide range of career paths that have been taken by past physics students is well illustrated by the results of a survey recently completed by Jerry Gollub of Haverford College. The box on page 51 lists the job titles of past Haverford physics graduates. David Dahl of Saint Olaf College compiled a similar list, and it too shows a huge range of possible jobs following a regular physics degree.

Given these apparent successes, one might conclude that all is well with the currently accepted undergraduate programs. However, from the frequently voiced comments of concern it is clear that all is not entirely well and that some changes will be needed to open up the field to a wider range of students. Sadly, the responses to the survey contained relatively little in the way of specific ideas in that direction.

For the undergraduate programs in applied physics and engineering physics the respondents generally indicated more positively that no major changes were desired, because they saw the programs as doing very well. As Kenneth Krane of Oregon State University wrote, "I am very satisfied with the program, which gives us a 'bridge' to engineering and also roughly doubles the number of 'physics' degrees we award. The 10–15 engineering physics degrees we award each year is small potatoes for the college of engineering, but the number of degrees and the increased students in upper-division physics classes help keep the wolf from our doors in these difficult budgetary times."

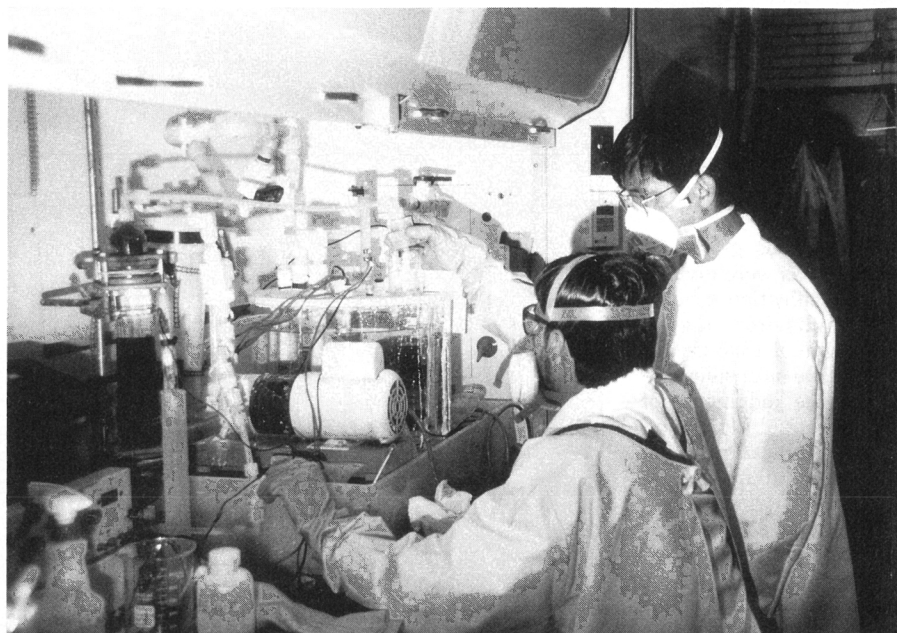
Graduate programs

Survey questions on the graduate programs aimed to identify new and unusual features in existing programs, gather comments on students' preparation for jobs and identify changes that might improve their preparation. In response to current calls for more "applied" research programs, I tried to collect opinions on what, if anything, distinguishes research in "pure" physics from that in "applied" physics or engineering. I also attempted to obtain a picture, albeit a subjective one, on the current balance between "pure" and "applied" research at the responding universities.

Graduate curriculum. As might be expected, there was much less uniformity in the course requirements at the graduate level than at the undergraduate level. Most institutions do not seem to have very specific course requirements as such and rely on some sort of qualifying procedure to ensure that students are adequately prepared for research. Some offer large numbers of courses beyond the usual central core, and a few actually require a minor outside physics, but generally graduate students seem relatively free to take courses as they see fit.

There were some comments on whether students could (or should) be allowed to do PhD theses with advisers outside the physics department. The questionnaire did not actually address that question, but it would appear that a number of institutions allow this practice, provided the research is still considered physics.

'Pure' and 'applied' physics. The question "What, if anything, distinguishes pure from applied physics?"



Photovoltaics research in the physics department at the Colorado School of Mines involves electrochemical processing for solar cells. Graduate student Scott Pozder (left) and research assistant professor Donghwan Kim consider manufacturability as well as the basic physics of the devices as they develop their techniques. (Courtesy of John Trefny.)

produced a wealth of answers. Several agreed with the definition that pure physics is "primarily directed to understanding fundamental laws of nature," while applied physics is "primarily directed to understanding phenomena of interest for practical application." For example, Jean Buehlman of the University of Wisconsin commented: "Good applied physics must have impact that is practical and essentially immediate. By contrast, good pure physics must provide new insights into questions that are currently considered of fundamental importance, and often have no practical (that is, economic) importance."

On the other hand, Ronald Reifenberger at Purdue strongly disagreed with such a narrow definition of physics, and wrote: "Physics is directed toward an understanding of how and why things work. By limiting pure physics to 'understanding fundamental laws of nature' one overstates the importance of the effort."

The broad point of view was also stressed by Roy Clarke, director of the program in applied physics at the University of Michigan, who wrote: "To me, this distinction has no useful role in the current status of our subject. The future of physics rests with the ability of physicists to bring their 'method' to bear on important problems directly affecting society (environment, health care, security, industrial strength . . .). Maybe it was always so. My view is that the 'applications' of physics (in the broadest sense of how physics affects society) are our *raison d'être*, and so its connections to other disciplines are its future."

A more narrow point of view was perhaps illustrated by the failure of a number of responses to address the question at all. The existence of such an attitude was confirmed by numerous comments made in telephone conversations to the effect that the real problem facing physics today is the arrogance of many physicists, who have long been isolated from industry and the real world and who simply do not see addressing societal needs as their province. Such physicists do not want to recognize anything different as "proper" physics. If someone moves outside their narrow definition of physics, he or she has simply "left physics," and anyone thus diverted is rarely

invited back.

One serious consequence of this narrow point of view is that students tend to lack role models for exploring new ways to use their physics skills. In part, this may be a generational problem, which will solve itself as some of the more traditionally trained faculty retire.

There was general agreement on the importance of motivation in distinguishing pure from applied physics. As Buehlman put it: "From the student's point of view, there is probably little difference between pure and applied research as far as day-to-day work is concerned. In both cases the work typically involves data collection, hardware and electronics design, computer-based data analysis, solving technical problems and so on. The main difference may well be in the motivation of the research."

Nobel laureate Arthur Schawlow, of Stanford University, illustrated the matter of motivation by citing the work of Calvin Quate: "When Cal was using his acoustic microscope to look for defects in integrated circuits, that was applied physics. But when his scanning microscopes were applied to study surface structures on an atomic scale that was, at least for the time, pure physics. The choice of topics in physics comes down to an aesthetic judgment. Is this going to change our view of physics?" But then, concerned that his remark might be construed as overly restrictive, he added, "The task of physics is not only to understand the hydrogen atom, but to understand the world." Obviously, the boundaries change all the time. Schawlow quoted a saying from jazz: "You can put cats into categories, but you can't keep them there."

If such a flexible point of view were generally accepted, much of the current discussion of basic versus applied science would disappear. Interdisciplinary connections would be encouraged, and the boundaries would be blurred. Physics undergraduates would learn that ideas in physics can often lead to developments in other fields and that such developments can be both interesting and important. Many, but unfortunately not all, physicists recognize this today.

To obtain a more quantitative estimate of the balance between pure and applied research in universities today, I asked respondents to indicate on a scale of 1–7 how

New technology based on ideas from pure physics.

Graduate student Kouros Ghandehari is working on a laser-ionization mass spectrometer developed in Cornell University's school of engineering and applied physics. Potential applications include monitoring trace emissions during the combustion of hazardous wastes.

"applied" they judged the research of various groups in their departments to be. The research areas were divided into 26 categories, according to the classification scheme used by AIP. Table 2 shows the results from the 24 responding universities, which have a total of 1695 graduate students. It is clear that such data have a considerable amount of uncertainty, both because the judgments of "how pure" or "how applied" are somewhat subjective and because there is inevitable overlap among the 26 research areas. Nevertheless the results do show a number of interesting features.

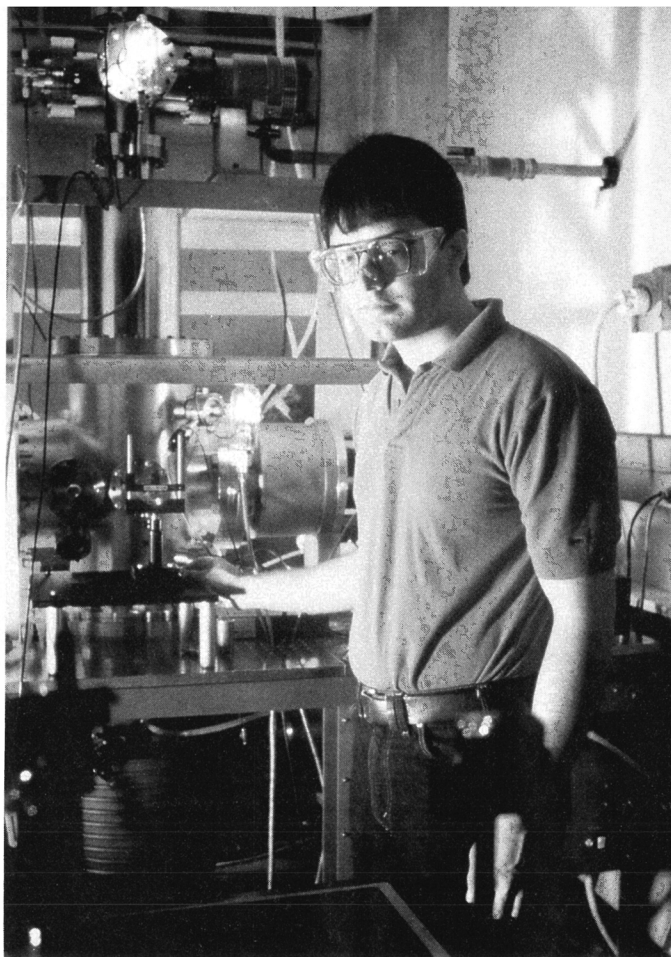
First, it can be seen that the areas judged to be most applied tend to have relatively small numbers of students. This is perhaps not surprising, since only 25% of the responding universities had programs with "applied" or "engineering" physics in their titles. Because this fraction is smaller for departments in the country as a whole, the balance nationally probably tends even more toward the "pure" side.

If one sums the total numbers of students in each category of the pure-applied rating over *all* research areas, one finds, as might be expected, that the numbers are largest on the pure side. A bit surprising was that the numbers for the more applied categories were only a factor of four smaller, showing that even now significant numbers of graduate students do work on quite "applied" research. A more extensive study of this kind might be of interest.

Comments on graduate programs. The survey asked for comments on a number of questions, including how well students were prepared for jobs. Perhaps the most surprising result was that a large number of respondents chose not to answer that question. Those who did generally felt that students were well prepared. Buehlman summarized the situation as follows: "It is clear that all students spend a portion of their graduate career learning specialized techniques and detailed facts that are of little use outside the area of specialization. However, the main usefulness of research at the PhD level is that students learn how to attack complex technical problems. At least for the best students, the experience of solving complex problems leads to a level of self-confidence and resourcefulness that carries over into any career."

One can only add to this that one must hope that students will not be disappointed if, as is increasingly the case, the environments in which they find themselves employed are very different from those in which they did their PhD research.

PHYSICS TODAY recently began a series of reports under the banner "Career Choices," describing unusual jobs taken by PhD physicists. Four reports have appeared so far: "A Physicist Carves a Niche in Industrial Ecology" (April 1993, page 39), "Teaching Computers to Translate Japanese" (July 1993, page 57), "A Board-Certified Physicist in Radiation Therapy" (September 1993, page 47) and "The Physics of High Finance" (June 1994, page 55). These and other examples provide evidence that students willing to be creative can find excellent jobs that combine some of the basic skills in physics with other disciplines.



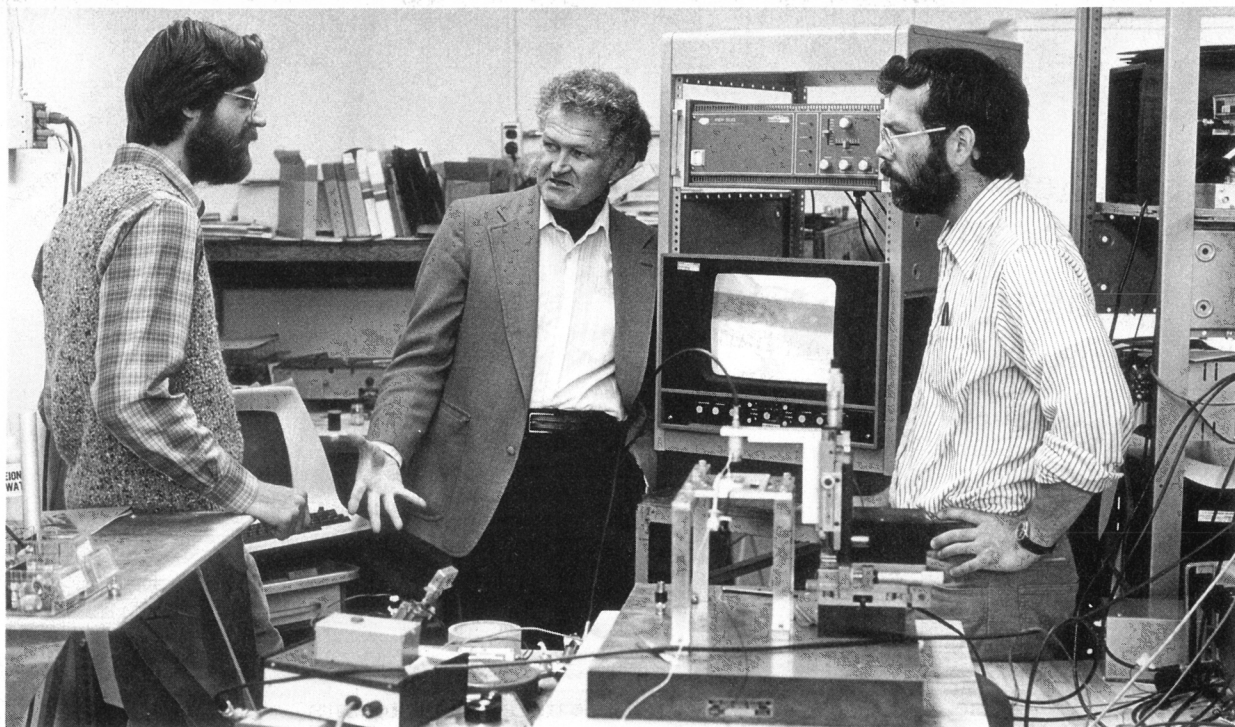
CHARLES HARRINGTON

Ideas for the future

There can be little doubt about two aspects of future developments in the education of physicists: Changes must come, and they are more likely to be evolutionary than revolutionary. Some changes will occur by the addition of new courses or the gradual evolution of existing courses to include new materials reflecting the growing breadth of the field. Books will be rewritten, new interactive CDs will be produced, and computers will become an ever growing part of the curriculum as younger faculty who have grown up with the computer take over.

However, the addition and modification of courses alone will not produce the needed change in *outlook*. Without destroying what is so powerful about a physics training, we need to make students and faculty more aware of the broadening scope and opportunities for physicists to work on problems that are important to society as well as to science. A number of means to increase this awareness suggest themselves.

Short courses of various kinds could be very effective. Outside lecturers could be brought in for, say, six or eight lectures, or faculty members themselves could be encouraged to develop short courses using materials gathered at intense workshops offered in conjunction with conferences. If administrators balk at giving students credit for such short courses, several could be strung together under an umbrella title such as "Special Topics in XYZ." The role of colloquia and noncredit seminars could be enlarged to encompass topics outside the narrower domain of physics, using a program similar to the very successful Visiting



Acoustic microscope research has both "pure" and "applied" aspects. Shown here in 1983 at Stanford University's Ginzton Laboratory are applied physics professor Calvin Quate (center) and graduate students John Hildebrand (left) and Robert Bray. (Courtesy of Quate.)

Industrial Physicist program run by APS in the late 1970s.² A few well-planted seeds might go far to encourage students to start thinking about a whole range of unconventional career tracks.

Another approach might be to develop new minors in fields adjacent to physics. Taken together with a common core of physics courses, a relatively small number of additional courses can give the student quite a good working knowledge in a second field. At Princeton, for example, students majoring in physics can obtain a certificate in materials science and engineering by taking only two required courses in that subject together with suitably selected electives and research topics. One requirement for such a program is close collaboration between departments, which may be a problem if they are in different schools.

An extension of this idea is the terminal master's degree. NSF Director Neal Lane advocated programs granting such degrees in a recent PHYSICS TODAY roundtable discussion (March 1994, page 30). Such programs are relatively rare in the US compared with other countries, but the reason for this is perhaps largely psychological: Rather than thinking of the master's degree recipient as holding a kind of "super bachelor of science," we tend to regard the individual as a "failed PhD." In part the problem lies in the courses that master's students are required to take. Generally they are the same as those taken by regular PhD students, which tend to be quite theoretical and geared to advanced research rather than to broadening the student's general training. Thus a student who stops his or her studies at this point is likely to be regarded as a basic researcher who didn't make it.

It is possible to design specific master's programs to avoid this trap. The one that has been running at the Georgia Institute of Technology for many years is a good example of the potential for a program of this kind. One

role the university running such a program must play is to educate potential employers and help establish contacts with employers that eventually become self-sustaining.

Educating physicists for the future will require changes at all levels, but one principle will have to be recognized: While there will always be room for physicists in narrow specialties, the number of such specialists cannot keep expanding. If physics is to thrive, its practitioners will have to learn to address broad classes of problems, to be flexible and to deal with complexity wherever it arises. In 1986, when jobs were still plentiful, PHYSICS TODAY's Bruce Schechter, discussing physicists in industry, wrote, "In a rapidly changing environment, the adaptable survive" (June 1986, page 58).

With the environment for science changing ever more rapidly, adaptability and flexibility will become even more essential.

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I thank the more than 50 department chairs and program directors who responded to the questionnaire, and the many colleagues who encouraged me in conversations. I specially want to thank Robert Birgeneau, Peter Franken, Gloria Lubkin, Abbas Ourmazd, Arthur Schawlow and Samuel Williamson for stimulating discussions; Roman Czujko, Jayne Miller and Elizabeth Wolf for valuable help with the questionnaire; and Jerry Gollub for making available the results of his survey. I also want to apologize to the many respondents whose excellent comments I could not include for lack of space.

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1. S. Tobias, APS News, April 1994, p. 8.
2. W. P. Wolf, in *Proc. Int. Conf. on Postgraduate Education of Physicists*, P. J. Kennedy, K. Vacek, eds., Int. Committee on Physics Education, U. of Edinburgh, Scotland (1981), p. 123. ■