

Preparing students for physics-related jobs

To keep pace with the changing times, physics departments should offer courses and major curricula in interdisciplinary fields as well as encourage more applied research.

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Physicists are now searching for new and alternative paths for the progress of their profession through the many problems surfacing in the 1970's. During the golden years of the last decade, we in the academic world felt secure and self-contained; we did physics and we taught physics. But the growing cutbacks in funds and in job opportunities have caused us to re-evaluate our personal goals, our responsibility to the larger society and our interactions with governmental, industrial and educational institutions. The business of training physicists is no longer a viable support for the avocation of doing physics. An obvious solution to these problems is for the academic physicist to offer his talent to a wider market, to move into physics-related fields, to engage in interdisciplinary efforts to solve current social, economic and scientific problems and to offer training that will prepare students for physics-related jobs.

In this article, I will point out the obstacles that exist to extending the scope of physics training in our school systems, undergraduate programs and graduate programs. I will also offer suggestions that might help to overcome these obstacles; principally, I will discuss participation in interdisciplinary programs particularly at the undergraduate level. I will present data from various studies, give some concrete examples of programs that are currently being carried out and propose organizational structures that might be used to implement new programs.

Problems in undergraduate education

About half of the students who receive bachelors' degrees in physics earn

them at institutions that offer the PhD as well as lower degrees in physics (see Table 1). Obviously all of the MS and PhD degrees in physics are awarded at the 300 or so universities that have graduate-physics programs. Nearly all of these institutions are organized along departmental lines. The science disciplines represented usually include physics, chemistry, biology and geology; a number of universities divide biology, and sometimes the physical-science disciplines, into smaller subdivisions.

Tendencies in other directions toward interdisciplinary organization exist but are confined to a relatively small number of institutions. Departments of "earth sciences" and "space sciences" are fairly common, but physicists have played almost no role in such mergers. At my own university, SUNY-Stony Brook, there is an Earth and Space-Sciences Department; the interaction between this department and the Physics Department is small. Despite increasing student interest in and research support for interdisciplinary areas that include physics (for example, the NSF "Research Applied to National Needs" program), undergraduate students committed to a physics department realize little benefit from these new opportunities. Biophysics is often, though not invariably, associated with a biology department, and when it is part of a physics department it is almost always confined to the graduate level. Geophysics generally resides in geology departments; those topics classified as chemical physics or physical chemistry are generally taught by chemists as part of chemistry courses. Oceanography and meteorology, though they rely heavily on physics principles, are taught by earth- and space-science departments. Materials sciences and urban science, though classified as science and concerned with data col-

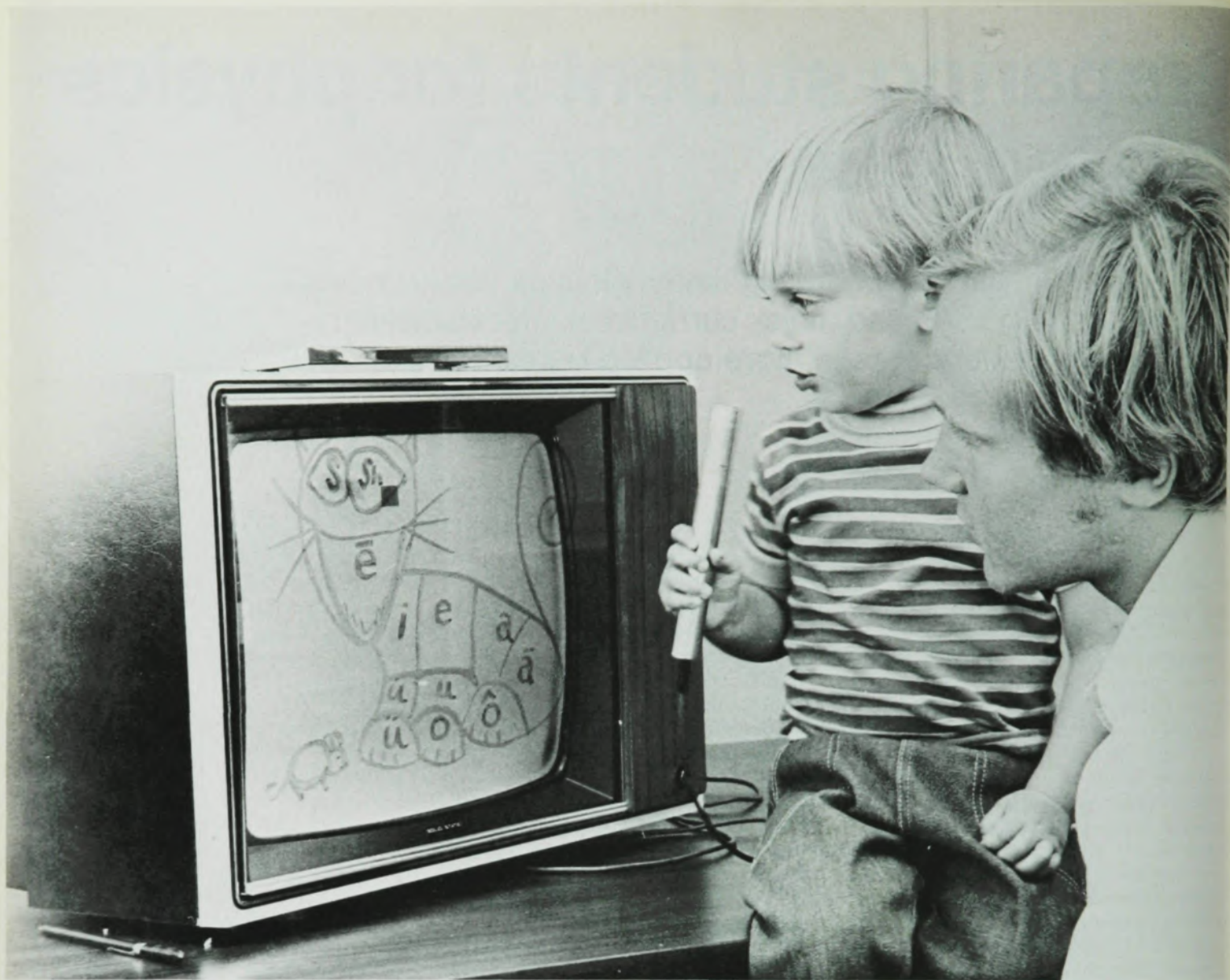
lection, the establishment of quantitative relationships among variables, and model building, are more likely to be part of engineering than physics departments.

Of course, many special institutes and research groups have been established on campuses and at government laboratories for the study of problems that require input from natural scientists and social scientists representing various traditional disciplines. Examples are the program in Urban and Policy Science at Stony Brook and the NASA Lunar Science Institute. These offer research opportunities in interdisciplinary fields to post graduates and graduates, but they seldom have any impact on undergraduate students.

Some efforts to broaden physics education have begun in physics departments at the graduate level. Virgil Elings and David Phillips of the physics departments at the University of California Santa Barbara have described an interdisciplinary graduate curriculum in scientific instrumentation.¹ In this program, which awards a master's degree, students participate in the work of a variety of laboratories doing research in biology, chemistry, engineering, physiology and physics. Figure 1 shows a picture of Michael Buchin, a student in the program who did his undergraduate work in physics, watching a deaf child use a speech display that he designed and constructed.

Opportunities exist for persons with physics training to move into new areas—even when their training was not designed to facilitate such shifts. Ronald Lee conducted a survey of opportunities open to undergraduate physics majors for graduate study in other fields.² The results, shown in figure 2, support the conclusion that graduate study in another field is an attractive direction to be considered by physics undergraduates and that under-

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A deaf child using a speech display and Michael Buchin, a student in the interdisciplinary master's degree program at the University of California at Santa Barbara. Buchin, who did his undergraduate work in physics, designed and constructed the display, which moves a black spot on the TV screen to a position corresponding to the sound made by the child. The development of this program was supported by an NSF grant. Figure 1

graduate study of physics can be a fruitful beginning to a career involved with multidisciplinary solutions to many of the current social, economic and environmental problems. Undoubtedly, this flow of students from undergraduate physics to careers in other fields could be increased if physics departments took a broader and more imaginative view of their mission.

Our traditional physics departments are lagging behind. Interdisciplinary programs do increase the range of opportunities available to physics students, but to take advantage of them, a student must transfer out of the physics department, wait until he or she becomes a graduate student, or both.

Present undergraduate situation

Many physicists will find nothing alarming about the situation described so far. They would argue that interdisciplinary science areas cannot be

understood until a firm background in the basic principles of traditional disciplines is attained. I agree that every serious science student should begin with courses—including physics—that stress basic principles in a quantitative manner. Elementary courses with such titles as "environmental science" that precede basic physics and biology make no sense as part of the preparation of future scientists. However, I see no good reason why a student who has diligently studied college physics, chemistry and biology for two years could not then profit from junior and senior courses in biophysics, atmospheric science, materials science or any one of several other interdisciplinary specialties that he or she wishes to pursue. It is certainly not necessary for a student with an interest in oceanography to take entire courses in mechanics, thermodynamics, botany and organic chemistry to learn the parts of these specialized subjects that apply to

his own particular career interests.

Not all the departments related to interdisciplinary sciences have vested interests in promoting majors in these fields; this means that the essential ingredients of a good major program—or even a collection of suitable courses—will not become available at most universities. In addition, the preoccupation of departments with their own disciplines has effects beyond the lost career opportunities in interdisciplinary fields. Most scientists are capable of identifying how their specialties contribute to such career activities as teaching, writing, medicine, law and business administration, but they show little motivation to design courses that contribute to career opportunities so far removed from their own career. The strong cohesiveness of physics departments encourage attitudes that make it unattractive—or even professionally disastrous—for a faculty member, particularly one without tenure, to

devote time to the education of non-physics science majors. While the need for students has neutralized these attitudes somewhat in recent years, the curricular inventiveness of most physics departments has been directed at nonscience majors, not at the career interests of students who could profit from more physics-related instruction than an introductory course but less than a physics major. No matter how we may view the value of a strong departmental structure, the fact is the number of jobs available in the research-intensive disciplines is declining. Unless departments identify how they can contribute to the preparation of students for the increasing number of jobs that involve the delivery of services rather than the production of goods, they will become less and less viable as organizational units on the campus. Table 2 provides data on enrollments in physics-related courses given by physics departments in 850 sampled institutions. Of these, only 218 institutions reported enrollment in physics-related courses.

Possible solution

By now it must be clear that I view problems in preparing students at the undergraduate level for physics-related jobs as being primarily political in nature. There is no doubt in my mind that the faculties of our universities could design excellent courses and curricula for almost any physics-related career if they took the time to identify the requirements of the career and if individuals representing the relevant disciplines would cooperate in the effort. To cite a few examples: Preston Forbes has described³ an interdisciplinary nuclear-science course, suitable for a liberal-arts college, that was given at Heidelberg College; David Onn, of the University of Delaware, reported⁴ on a medical-physics course based upon hospital field experience; Priscilla Laws, from the physics department at Dickinson College, has made an attempt⁵ to define the ways in which a physical scientist can contribute to an interdisciplinary course. In addition to these courses reported in the literature, the following interdisciplinary courses can be found under "physics" in undergraduate college catalogues:

- Principles of Geophysics: University of Arizona
- Planetary Physics: University of Hawaii
- Atmospheric Physics: Oregon State University
- Introduction to Materials Science: University of Pennsylvania
- Introduction to Astrophysics: Texas A. and M. University
- Medical Physics: University of Wisconsin.

I will not dwell any further on specif-

ic examples. Instead I will make some suggestions concerning organizational structures conducive to curricular innovation in nontraditional areas. Institutions without graduate programs should seriously consider eliminating departments and replacing them with groups of faculty members with common interests in specific undergraduate programs. (Such a plan would not, of course, preclude the existence of a physics program.) This would not be just a different way of sorting faculty into static administrative units. The primary goal of this plan would be to focus attention on what educational programs are to be offered undergraduates, not to identify and isolate the research specialties of the faculty. Individual faculty members could belong to one or more such units at any one time depending on the current thrust of their instructional efforts. These associations could change from time to time. Budgets would be made to support programs; salaries would be charged to these budgets. The research activities of faculty members would continue in whatever fields interest them. Support for this research would be provided from funds budgeted for research and administered by a dean in a central office. In this way the impact of research on the entire campus could be better evaluated and more easily influenced by all concerned. Structures of this type have been tried by a few new colleges and they do work. For example, the School of Engineering at Rensselaer Polytechnic Institute operates with a "grid structure" that includes the features described above.⁶

Grid structures can be constructed in various ways, but always involve at least a two-dimensional array designed to provide a basis for grouping faculty efforts and budgeting academic resources more broadly than on purely disciplinary lines. In one variation, areas of research competence would be listed along one axis and possible student careers along the other. The ac-

tivities of traditional academic physicists would fall on the intersection of such research fields as "nuclear structure" with the career goal "academic research." In the grid approach, a cluster of points could be identified where such research fields as "applied physics," "applied mathematics," "engineering processes," and "industrial management" intersect career goals such as "systems analysis," "computer programming" and "industrial management." Both research projects and courses could be associated with faculty assigned to this cluster, and budgets would be developed to reflect the goals of these programs for a number of years commensurate with the vitality of the programs and the cohesiveness of the mutual interests that caused the cluster to form initially.

For universities with large commitments to graduate education and research, a grid structure will probably be unattractive and perhaps unsuitable. A less drastic maneuver would be to encourage the development of interdisciplinary courses and major curricula by adopting bookkeeping procedures that would appropriately reward those willing to participate. In my opinion, many scientists would happily involve themselves in innovative instructional ventures if there was encouragement and approval at the department level. With departmental economics being what they are, the promise of more students that would justify more faculty without the risk of losing support for cherished ongoing activities would probably be sufficient to stimulate considerable innovation. This could be accomplished by following two procedures: First, credit each cooperating department with a fair share of the student enrollments in the new program; second, invest from a central budget for curricular innovation those operating costs other than salaries necessary to support a three-year trial. If after three years the program has attracted few students, it should be dropped. If students are en-

Table 1. Number of BS Degrees Awarded Annually in Physics

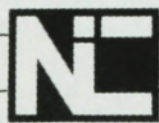
Years	PhD-granting Institutions	MS-granting Institutions	BS-granting Institutions
1965-66	2482	955	1600
1966-67	2630	911	1695
1967-68	2816	1016	1690
1968-69	2994	1029	1952
1969-70	3036	1022	1724
1970-71	2868	1044	1843
1971-72	2502	982	1798

Data taken from "Physics and Astronomy Enrollments and Degrees in the US," AIP, March, 1973.

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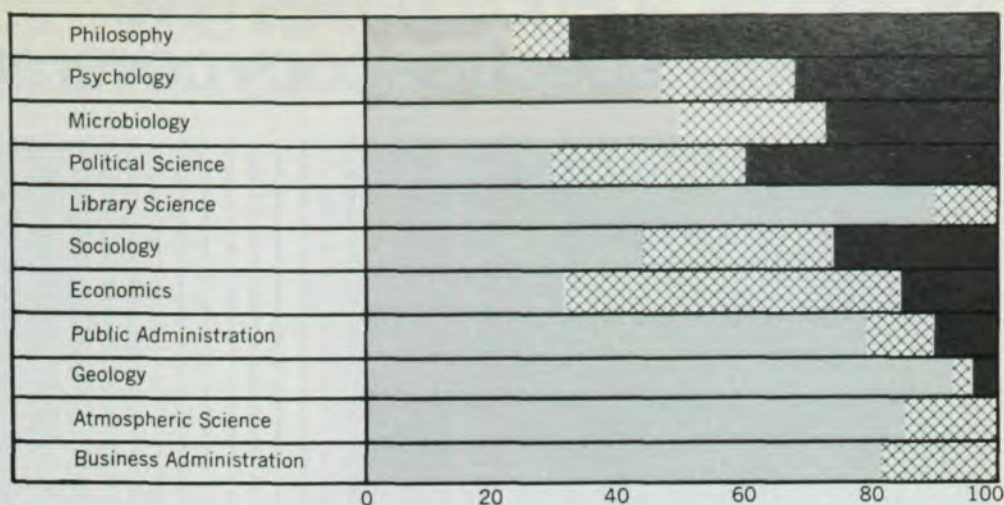
rolled, the departments will surely be willing to absorb operational costs in order to retain faculty credits for student enrollments.

Graduate programs

What can be done at the graduate level within the framework of existing departmental structures to improve the preparation of physics students for physics-related jobs? In my view, the most urgent need is for more opportunities in applied research. The "Work Complex Study," conducted by Susanne Ellis of the AIP Manpower Division,⁷ established that many industrial laboratories prefer graduate engineers to physicists largely because they are more experienced in coping with practical problems and more willing to attack them. Can a physics department respond meaningfully to this challenge? I think they can. The main problem is one of attitude. In the golden years, applied research simply did not have the same prestige as basic research. This prevented many faculty members who possess the necessary talents and interests from studying applied problems. So the first need is to recognize that any legitimate activity pursued with energy and talent is respectable, and if it contributes to the welfare of society, it should be supported and admired.

But agreeing that applied research is good will not suddenly produce opportunities within graduate physics programs. I can conceive of two mechanisms that would expand the opportunities of graduate students. First, there do exist on many campuses applied-research opportunities that involve physics strongly but do not involve physicists. Materials-science research, usually conducted by engineers, provides an obvious example. I suggest that we allow physics graduate students, once they have satisfied course requirements for PhD candidacy, to satisfy their thesis requirement by working under the supervision of an engineer, a chemist, a geologist or a faculty member associated with one of the special research institutes common on college campuses today.

The second suggestion, if implemented, would require greater cooperation with industrial and government laboratories than has been customary heretofore. As long as the quality of the research performed is monitored by a faculty member from the degree-granting institution, I see no reason why a graduate student should not conduct his thesis research in any physics laboratory that has the facilities and personnel to support the kind of applied research he or she would like to pursue. The benefits from such cooperative activities would extend beyond the immediate values to the stu-



The Lee survey of opportunities open to physics majors for graduate study in other fields. In the survey, 317 department heads at 73 universities were asked about a typical (hypothetical) physics major. The data is shown here for one of the questions: How desirable would the hypothetical student be for their graduate program? The light bar gives the percentage of departments that considered the typical student to be very desirable for their program. The patterned bar gives the percentage of departments that considered the typical student to be adequate for their program. The dark bar gives the percentage of departments feeling that the typical student was marginal or unacceptable for their program. This graph was taken from reference 2.

Figure 2

dent involved in this type of program.

There are existence proofs that the ivy-covered walls do not come tumbling down when a graduate student performs thesis research off campus. For many years physics graduate students in the New York and Chicago areas have had access to facilities at Brookhaven and Argonne respectively, and several national laboratories, Oak Ridge for one, have organized groups of university associates to encourage exchanges of faculty and to stimulate other kinds of laboratory-university interactions. These kinds of programs take a step in the right direction, but they do not accomplish all that I am now recommending.

The need is not just to prove to graduate students that legitimate research is conducted in nonacademic laboratories, but to provide opportunities for students to become involved in applied research, and to convince them that such work is worthy of their best creative efforts. In my view, this can only be accomplished with the full cooperation of industry. I have a small amount of privately collected evidence that industry would be pleased to cooperate. However, each physics department that wishes to provide industrial research experience for their graduate students must take the initiative itself, and this step presents an unfortunate barrier. One department with which I consulted had committed itself to a graduate-level program in technical physics, but was unable to take the next step because they had no working relationship with any industrial physicists, even though the university was located in a heavily industrialized

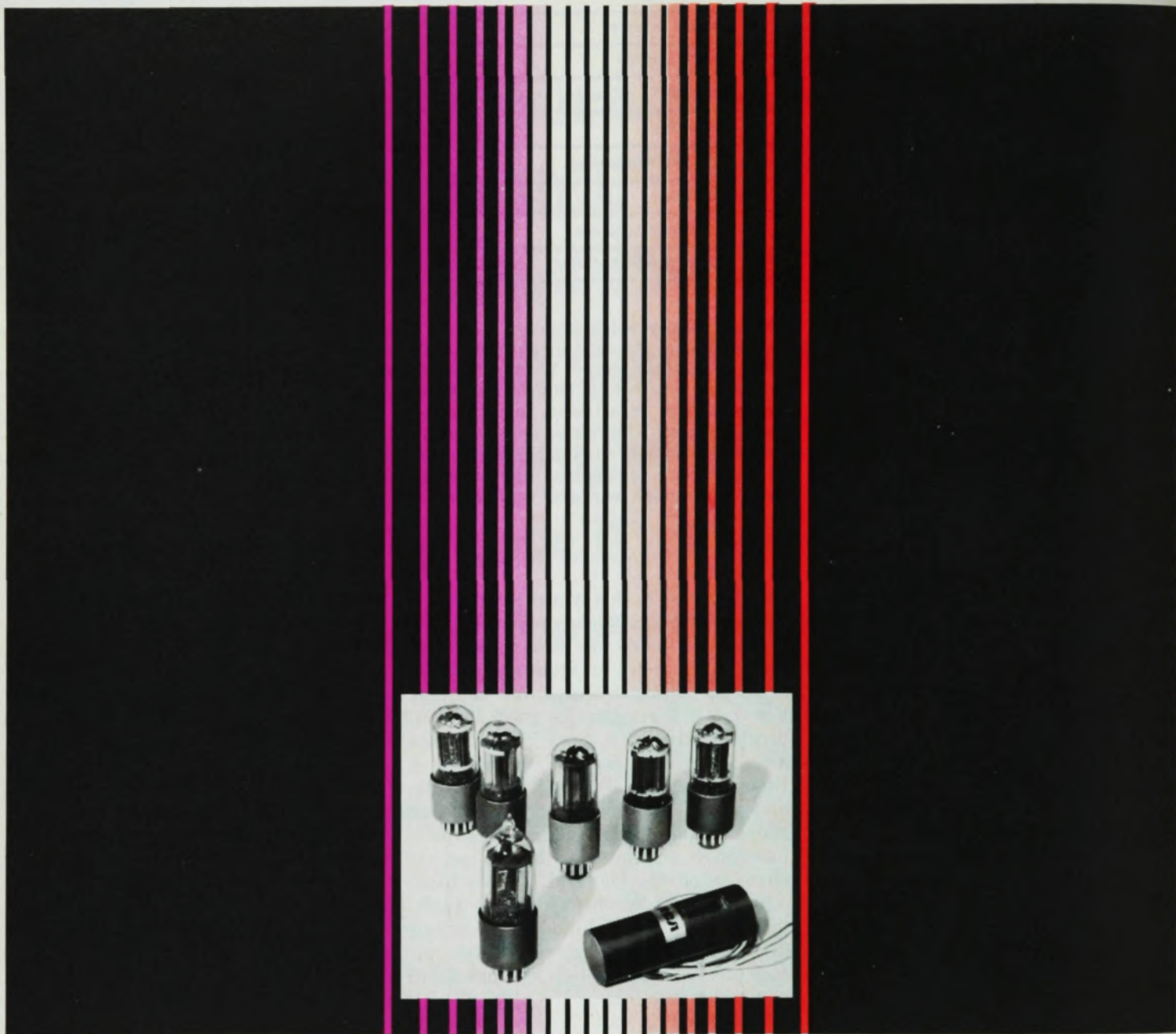
area! Perhaps the joint meeting of AIP Corporate Associates and the group of prospective academic associates, held in September, will help to initiate a new kind of relationship that will make proposals like mine easier to implement.

Beginning science education

In preparing students for physics-related jobs, as in so many areas, the problems really begin at a very early age. Science, both as a primary activity and in terms of its secondary role in all sorts of individual careers and public programs, is poorly presented by pre-college teachers and badly understood by young students and other citizens. We should not be surprised that troubles exist at the college level for all but the few who are willing and able to emulate their college professors.

In my opinion, there is no cure for this ill other than to attract better students to pre-college teaching and to provide these students with a much higher quality teacher-preparation program. Fortunately teacher salaries and working conditions have improved significantly. This, plus the fact that many young people are now interested in social service, has resulted in a situation allowing careful selection of teacher candidates from among many who are apparently well qualified and deeply committed. However, the college teacher-preparation programs still need much improvement. I believe adequate programs will become common only when the most able scientists share with educators the responsibility of designing and teaching better subject-matter courses, and supervising

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If we had better-trained elementary-school teachers, we could anticipate significant improvement in the attitudes of college students and citizens toward science and in their abilities to deal intelligently with more advanced science concepts and with technology. This optimism stems from my belief that the quality of the elementary-school science teaching materials that have become available during the past ten years is now far superior to the ability of the teachers to use them effectively. The key to effective elementary-level science teaching, in my view, is to stress observation, logical deduction from facts and premises to conclusions, and model-making. Such process-oriented courses have been constructed by many talented scientists and await effective exploitation.

At the secondary-school level, the situation is not as healthy. The same disease of disciplinary isolation and arrogance discussed above in connection with colleges also infects secondary-school science departments. One symptom it creates is an excessive concern for subject-matter content. It appears ludicrous to me that arguments should rage concerning the order of teaching physics, chemistry and biology in high school when the general scientific literacy of high-school students is so low that many of them cannot distinguish the principles and techniques of one discipline from another. After all, the really basic principles

are common to all the disciplines, and study techniques differ significantly only at higher levels than can be achieved in high school. A devastating side effect resulting from pretentiousness is that most students learn almost no science when in high school because the content and pace is beyond their intellectual capabilities.

Some steps have been taken toward the development of an interdisciplinary high-school science course dealing with problems of interest to teenagers at a level that the majority of them could comprehend. The name of one project is "Individualized Science Instructional Systems;" it is housed on the campus of Florida State University and is directed by Ernest Burkman, whose unpublished report contains valuable information. Another project, headed by Earl Zwicker of the physics department at the Illinois Institute of Technology was designed for inner-city school systems. Funded by a \$37 000 NSF grant, the summer institute sought to reach the teachers and students and to stimulate their interest in science and technology. During the course of the institute, the teachers constructed apparatus that they will be using this school year in their classes.

This concern about pre-college science is not irrelevant; I am persuaded that better pre-college science experiences would make science-related careers more attractive to college students and would make suitable specialized college science programs easier to design and implement. To support this contention, I cite a study by W. R.

Snelling and R. F. Boruch revealing that commitments to careers in science are made long before college for most students.⁸ I submit that it is essential to convince students early that science can contribute to the improvement of the quality of life without creating new social and technological problems if we are to attract young people into para-professional science-related careers.

What can be done?

Everyone agrees that we are in a period of rapid change. It seems paradoxical that the universities—bastions of research and hence leaders in promoting new ideas and advanced technology in previous decades—should now be slower than industrial and governmental organizations to recognize the current needs of society for skilled employees and to adopt effective training methods for meeting these needs. Clearly the universities (and particularly physics departments) must review their goals and procedures. Change is needed to guarantee self-preservation and useful productivity.

As a beginning, I recommend the following steps:

- Improve the preparation of elementary-school teachers, so that proper use can be made of already existing elementary-science materials. Scientists should contribute to the design and teaching of college science courses for future teachers.
- Eliminate the disciplinary emphasis in secondary-school science courses. Offer science courses in high school at a level appropriate to the majority of students.
- Offer college courses and major curricula in interdisciplinary fields and other physics-related areas. Restructure administrative or bookkeeping systems to increase faculty motivation for involving themselves in the instruction of nonphysics majors.
- Increase the number and variety of opportunities for applied research at the graduate level. To accomplish this, make it possible for thesis research to be performed in campus research institutes or industrial laboratories.

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Table 2. Enrollment in Physics-Related Courses offered by Physics Departments

Courses	Enrollment
Astronomy	2 504
Astrophysics	530
Advanced engineering	6
Art technology	32
Biophysics	539
Computer science	374
Cybernetics	11
Development of physics	50
Electronics	9 780
Education	130
Environmental physics	383
Earth physics	115
Geology	114
Growth of science & its concepts	0
Issues of science & religion	0
Meteorology	358
Oceanography	59
Photography	300
Pre-med & biology	100
Philosophic physics	91
	15 476

Source: "Survey of Enrollments and Degrees in Physics" AIP Publication R-151.9