IV. THE EFFECT OF INSTRUMENT DEFICIENCIES ON THE CAREER PREPARATION OF B.S. RECIPIENTS IN SCIENCE AND ENGINEERING

The adequacy question — the question of whether students' laboratory experience has prepared them sufficiently for a career — is dependent upon the type of career they choose. Those students who wish merely to understand and use today's technology will clearly have more modest requirements than those who plan to advance the technology further. For example, anew engineer without any robotics experience can detrained by a company to use a robot if he or she is sufficiently trained in the related field of computers.[29] By contrast, for an engineer to understand how to modify or redesign a robot, he or she must first have used it as an experimental tool in an educational setting. 'Without working with (a robot), one can't design a factory with a robot," states Daniel Drucker, Graduate Research Professor of Engineering Science at the University of Florida at Gainesville. 'You can do what's already been done, but you don't have any idea of how to modify it."

Definitions of adequate hands-on training differ between engineering and the sciences. Because most baccalaureate level engineers go into industry upon graduation, the adequacy question is focused on undergraduate experience and the willingness of industry to provide on-the-job training. In the sciences, most undergraduates who choose a scientific career will go to graduate schooI for further training. In this case, the adequacy question is focused more on the student's preparedness for further academic pursuits. Because of these differences, OTA interviewed industry representatives and graduate school deans to determine if instrumentation deficiencies were having an impact on the quality of the pool of students from which each must draw.

29. Theodore Russo, Polaroid, Cambridge, MA, interview, 1985.

PREPARATION FOR INDUSTRIAL EMPLOYMENT

Members of academic institutions expressed concern that students trained on obsolete equipment will not be adequately prepared to enter industrial careers in their field. In response to this concern, OTA interviewed members of industries in two fields most heavily affected by technological changes in the past 20 years: engineering and chemistry.

Industry representatives were divided over whether or not new graduates have been sufficiently exposed to new equipment. Several managers in both engineering and chemistry stated that they found new graduates to be better prepared than at any other time in the last two decades. Other employers said they are spending more time training new employees in the use of modern equipment. For some managers, this increased training time appears to be a source of frustration. Most managers, however, accept that such training will be necessary, either because universities cannot afford to purchase certain kinds of equipment, such as computer-aided design equipment, or because of the narrow application of the equipment in a particular company.

Several industrial managers mentioned that other educational problems were of greater concern than equipment, e.g. the quality of faculty and the basic level of education of new employees.[30] In a survey of over 70 chemical companies by a task force of the American Chemical Society, English and communication skills were mentioned more frequently than updated equipment training as areas which needed improvement for undergraduate chemistry majors. Chemical companies also cited business and economics education just as often as equipment training as curriculum areas in need of shoring up.[31]

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30. Gerald Dinneen and Paul Petersen, Honeywell, Inc., Minneapolis, MN, interviews, 1985; Ed Wasserman, E.I. du Pont de Nemours Co., Wilmington, DE, interview, 1985.
31. American Chemical Society, Summary of the Final Report and Recommendation of the Task Force on Academic Preparation and Industrial Careers in Chemistry (Washington, DC: Feb. 15, 1984), p. 2.

In reviewing the comments of industry on this issue, it is important to recognize the different needs of different companies. A company that uses microprocessor equipment will clearly have different needs than one that manufactures or designs microprocessors. Thus a level of satisfaction with the educational experience of its recent graduates may differ from firm to firm, or even within divisions of a firm.

Several interviews have suggested that one of industry's responses to inadequate equipment training has been to shift from hiring baccalaureates to hiring applicants with graduate training.[32] This may be an important trend in the fields of electrical engineering and chemistry. However, the marketability of biology majors with undergraduate degrees has increased, owing to the growth of industrial activity and research in the field of biotechnology.

Engineering

Interviews were conducted with nine employers of engineers with undergraduate degrees. Employers in this field were divided over whether their new employees lacked necessary experience with modern equipment. Those employers who were satisfied with new graduates, including companies in the fast-moving computer business, frequently stated that they found new engineers better prepared than ever before.

Those employers who believed there were equipment problems at engineering colleges often found it difficult to demonstrate that new employees were any less well-qualified than previously because of equipment deficiencies at the undergraduate level. For example, Gerald Dinneen, Honeywell's Corporate Vice President of Science and Technology, believes that the primary impact of poor equipment at engineering colleges will be the eventual loss of discouraged faculty to industry. Dinneen reports that firms

32. Newman Bortnick, Rohm and Haas, Philadelphia, PA, interview, 1985; Darcy Brent, Bayard Corp., Bedford, MA, interview, 1985; and Joseph Arrigo, Des Plaines, IL, interview, 1985.

such as Honeywell are an increasingly attractive option for college faculty primarily because of superior equipment, not the salary difference. Yet, neither Dinneen nor Paul Petersen, who employs about 25 undergraduate degree engineers for Honeywell's Physical Sciences Center, find fault with new employees' preparation.

Petersen's concern is that schools are over-emphasizing technical education:

> In the universities we recruit from, the technical education is improving. Overall, education is on the decline. The universities are doing too much technical training. Students come out with very good technical skills but they are not strong enough in the associated fields, such as the English language and communications skills.

At General Electric, which hires 1,100 to 1,200 new engineering graduates per year, Robert N. Mills, chief recruiter for the company, believes 'the instrumentation is just terrible in these schools.˜ He could not say that the problem was reflected in new employees in a measurable way but noted that GE has increased its training in recent years. Today, about 50 percent more of GE's new engineers are taking the company's educational courses than 3 to 4 years ago, Mills said. The needs for training are in electronics, computer sciences, and CAD-CAM. Mills said his biggest concern is that equipment problems are producing inconsistent engineering education among schools, forcing the company to concentrate on a smaller number of schools for its hiring.

In general, most employers of engineers agreed that the basic level of equipment knowledge should include a strong working knowledge of personal computers and knowledge of at least one computer language. While many employers considered experience with digital laboratory equipment a minimum requirement, others considered the experience superfluous or an unrealistic expectation.

Demands obviously varied depending on the type of industry. For example, Wang Laboratories in Lowell, Massachusetts, a mini-computer manufacturer, expects engineering graduates to have worked on digital equipment and to be familiar with digital coding. Wang's Thomas Law, who is responsible for recruiting and hiring 30 to 80

engineers per year out of undergraduate schools, said his company found that new engineering students' knowledge of the computer field is up-to-date and he had no complaints.

Polaroid's Senior Technical Manager Theodore Russo — who hires new engineers in the areas of microelectronics, videotapes, and video printers — downplayed digital experience. Such experience does not, in his view, change ''basic understanding." Russo also said that the interface of laboratory equipment with computers was not a "big issue" and that the company had recently decided against converting one of its own laboratories in this direction on the grounds that it would not produce a large improvement in efficiency.

For a company like Ford Motor Co., the ability to interface computers with data-collection equipment is an extremely desirable skill, but Dale Compton, Ford's Vice President for Research, says it is hard to find anyone with that experience. Like many employers, Compton considers the new graduates lack of experience in the use of equipment to be more of a problem than in the past 15 years "because the technology is moving much faster and the equipment is more expensive. " He said that Ford is training more of its new employees, particularly in the interfacing of electronic to mechanical equipment.

Managers were asked to comment on the level of experience they had found and would expect to find on the following types of major equipment cited as needs by engineering schools:

- CAD-CAM-This experience is generally considered desirable, but most students are not expected to have significant experience because of the cost of equipment. Honeywell expects its new engineers, primarily hired from Midwestern State universities, to be familiar with the concept of computer-aided engineering and its application to problem solving. Russo of Polaroid suggested that a new generation of mini-CAD machines may eventually make this technology affordable to engineering schools.

- Rototics-Few managers expected to find B.A. engineers with extensive hands-on experience in this area, although some expected engineering students to be familiar with robots' abilities. At General Electric, which manufactures robots, Mills said, "We can't hope to have a B.A. who really knows all the variations of robotics, but we expect a well-qualified engineer of whatever discipline to have an awareness of what robots can do.'!

- Chemical Processing Equipment—Managers familiar with this area considered this equipment too expensive to be supplied at the state-of-the-art level in the universities. The same view was given for microprocessor manufacturing.

In a few specialized fields, such as opto-electronics and automotive R&D, employers said they expected to train employees on the job.

While many employers agreed that they were training more of their new engineers today than they had in the past 10 to 15 years, they disagreed as to whether this was the result of inferior education. Some managers accepted the fact that rapidly changing technologies would require ongoing training. Others suggested that schools should be doing a better job of preparing students, but they were not sure such expectations was realistic, given the cost of improvements.

Bayard Corp., which manufactures analytical instruments, no longer hires electrical engineers fresh out of engineering school. Vice President for Engineering Darcy Brent says the company relied heavily on B.A.s for its electrical engineers in the 1960s and 1970s. Starting in 1970, the company shifted to hiring M.A. degree engineers only for these slots. The reason, Brent says, is that Bayard's electrical engineers need experience in selecting and integrating microprocessors into analytical instruments. While undergraduate electrical engineers know the basic design aspects of microprocessors, Brent says, 'they don't know how to apply them to total systems.[w]

Bayard still relies on B.A.s to fill openings for mechanical engineers; Brent considers them 'a lot better than 10 years ago." He concurs with other managers, however, that mechanical engineers need additional training in CAD-CAM, 'but I don't see how the colleges can afford it." Similarly, he notes that the field of mechanical

engineering has changed sufficiently over the past decade to incorporate more electrical work and that the colleges are having trouble keeping up with this change. "In the general field of mechanical engineering, there is a shortage of people who know enough about electrical engineering, which now comprises about one-third of their field," Brent notes.

Chemistry

Few of those interviewed in the chemical industry view equipment proficiency for today's chemistry graduates as a major concern. Yet because of the consensus that chemistry instrumentation is changing dramatically, those employers most pleased with today's graduates worry whether these students represent the end of an era.

'We have never seen better prepared scientists and engineers than we are able to hire today,[v] states Dr. Alan McClelland, assistant to the director for the Central Research and Development Department of E.I. du Pent de Nemours Co. He attributes this level of quality to the government spending on education following Sputnik. However, McClelland goes on to say that "We're also seeing the running out of increased support[v] for science education that was spurred by the Sputnik era. Du Pent sees evidence of college and university difficulty in stocking laboratories in requests to the company for aid in the purchase and maintenance of academic equipment. Equipment-related requests to du Pent's educational fund have approximately doubled in the last 4 years. (Du Pent gives about $12 million annually in aid to education.)

Several employers of chemists say they are dealing with inadequate preparation of baccalaureate level chemists by hiring people with graduate degrees or by conducting additional training classes. Bayard Corp., mentioned above, stopped hiring analytical chemists with B.A.s in 1978 and now hires only chemists with degrees at the masters level or above. Other chemical companies, such as Rohm and Haas, hire B.A. chemists

primarily as technicians, relying on Ph. D.s and M.A.s for research.

Generally, employers agreed that while starting chemists are trained at a more advanced level than the previous generation, they still cannot keep up with the developments in equipment commonly used in industry. Du Pent's Ed Wasserman, Associate Director of Technology, Chemical Sciences Area, Central Research and Development, believes the net effect is that students are farther behind in their grasp of today's expanding field of chemistry than the previous generation.

The industry's requirements for students! equipment experience varies significantly from company to company. The importance of exposure to NMR at the undergraduate level provides an interesting benchmark of the different requirements and expectations employers have. According to du Pent's Wasserman, a chemistry B.S. 'should have extensive experience with NMR's.[n] A former manager for Exxon said sorne experience with NMR's would be expected. At the other end of the spectrum, Rohm and Haas' research director stated that at the undergraduate level, students have 'almost never used[fi] the instrumentation they will be working on at the company, including NMR's, spectroscopic equipment, chromatography, and high performance liquid chromatography. However, Dr. Newman Bortnick of Rohm and Haas does not appear dismayed by this lack of experience or the additional training required. 'What you need to understand is the methodology behind it (the equipment). You don't need 1985 equipment to understand it.[U]

Joseph Arrigo, until 1983 a manager with Universal Oil Products (UOP) in Des Plaines, Illinois, said that he expected new employees to have 'a good feel for what NMR's, gas chromatography, and mass spectrometers could do for them but no real proficiency hands-on . . . . We taught them in no time (days to a week)" how to use the instruments, he said. From Arrigo's perspective as a visiting college professor and as a company representative who gave career talks at colleges, the equipment inventory of different schools varies greatly.

'Beyond the first and second tier schools, it's a constant struggle to provide some

level of hands-on proficiency." Regarding schools without a stable of NIMR's, mass spectrometers, gas chromatography, and infrared spectrophoto meters, Arrigo said, "I don't know how kids could ever get out and walk into a job without exposure to these kinds of equipment."

The major concern of the firms interviewed by a task force of the American Chemical Society,[33] mentioned above, was that B.S. chemists are not sufficiently familiar with the way that chemistry is conducted in industry, as opposed to academic laboratories. A major problem mentioned was the lack of experience with independent problem solving in the laboratory — a concern related more to the method of teaching and the exposure to laboratory experimentation than to equipment per se.

GRADUATE SCHOOL PREPARATION

OTA interviewed graduate deans and faculty from all sections of the country to find out if equipment problems affect the quality of entering graduate students. Few of those interviewed were prepared to state that the quality of today's graduate students was definitely related to the level of exposure to new equipment. Several deans expressed concern, however, that new graduate students have had reduced hands-on laboratory experience. Several noted that this issue could arise during the application procedure in the discussion of the studentts laboratory experience, usually in connection with an honors thesis research project. However, it was not clear that an impressive research thesis would necessarily be dependent on the sophistication of the equipment used.

Interviews with graduate schools suggested that they view the current period as one of transition. On the one hand, graduate schools do not expect new graduates to be

33. American Chemical Society, Summary of the Final Report and Recommendation of the Task Force on Academic Preparation and Industrial Careers in Chemistry, op. cit., p. 2.

familiar with the use of sophisticated equipment because they understand the financial straits of most undergraduate departments. On the other hand, applicants with a high level of technical sophistication together with other criteria — such as grades and test scores— will increasingly receive more favorable treatment in the admissions process as research equipment becomes more affordable for colleges and more integrated into a basic understanding of the field. This was reflected in the comments of one of the deans who was interviewed.

> A chemistry student with no experience on NMR's will be at a loss when he comes to the University of Vermont. Undergraduates should have had a year% worth of experience on an NMR. They should know what it can do and how to operate it. 34tudents 'rem 4-year colleges probably will not have this experience.

Generally, graduate schools cited the same fields mentioned by undergraduate departments as those which have been most affected by equipment changes: chemistry, engineering, biology, and physics. In addition, graduate faculty suggested that the changing nature of such fields as chemistry and engineering would require that future undergraduates be familiar with sophisticated instrumentation.

> We don't expect [entering graduate] students to be exposed to NMR's. However, at Notre Dame, we like to put juniors and seniors in the research lab with NMR's. This is for the top IO percent of the class. [The electron microscope) used to be an ultra-research tooL Now it is very common to expect juniors and seniors to use it.

And while many graduate schools are concerned that entering students are poorly trained in the use of modern equipment, some feel that a good student will learn to use the equipment quickly if she has been schooled in the principles that underlie the machine's functions.

> They [entering graduate students] don't need to have used a high-resolution NMR or an electron microscope, but they need to understand the fundamentals of those instruments. We expect the student to be exposed to the principles of an NMR on a simple machine . . . . In the case of an electron microscope, understanding

34. Robert Lawson, Dean of the Graduate College and Associate Vice President for Research, University of Vermont, interview, 1985.
35. Robert Gordon, Vice President for Advanced Studies, Notre Dame, interview, 1985.

> the results is much [36]ore important in undergraduate learning than hands-on experience.
>
> My guess is we would expect students to have experience with an NMR in chemistry. That is a standard piece of equipment now. It is probably not important whether they know[37] how to use it the day they arrive as long as they pick it up quickly.

Engineering

Engineering faculty questioned on this issue noted that most engineering graduate students are not American and are often not the best students because of the high salaries commanded by B.S. engineers in industry. In general, they noted that entering graduate students were often not well-grounded in or not interested in laboratory experimentation. They agreed that few had extensive hands-on experience with the type of equipment listed above (Section II) as needed.

Dan Drucker, graduate research professor in the Engineering Science Department at the University of Florida at Gainesville, stated that the lack of undergraduate laboratory experience affects the quality of work done by graduate students. 'They are not going into experimentation in the numbers they should. They are substituting simulation for physical reality. Without experimentation, one isn't able to utilize physical behavior, which governs engineering. Students reproduce what's already known — which a computer can don

One faculty member, who agreed that computers had caused a revolution in technology, suggested that colleges were putting too much emphasis on the need for equipment and less on the need for inventive faculty. Myron Tribus, Director of the Center for Advanced Engineering Studies at MIT, notes that many schools are using foreign graduate students to teach very large courses in place of faculty, a pattern

36. Robert Bock, Graduate Dean, University of Wisconsin, interview, 1985.
37. Frank Perkins, Associate Provost and Dean of the Graduate School, Massachusetts Institute of Technology, Cambridge, MA, interview, 1985.

repeated at “90 percent of the engineering schools.” People get “more training than education, not creative programs,” Tribus said. ‘This requires off-the-shelf equipment . . . . These colleges are trying to buy with equipment what they can’t buy with personnel.[n] In contrast, Tribus described the approach taken at Dartmouth, where he was Dean of Engineering for 10 years. Dartmouth faculty designed and developed their own equipment, which required a heavier investment of faculty time than usual. Dartmouth engineering graduates, he said, ‘will not become obsolete˜ because they understand the fundamentals.