Scientific Equipment for Undergraduates: Is It Adequate?

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TABLE OF CONTENTS

SCIENTIFIC EQUIPMENT FOR UNDERGRADUATES: IS IT ADEQUATE?

INTRODUCTION

At the request of Chairman Orrin G. Hatch and Senator Christopher J. Dodd of the Senate Committee on Labor and Human Resources, the Office of Technology Assessment (OTA) conducted a review of the adequacy of instructional equipment used to teach science and engineering to undergraduate students at American colleges and universities. An interview was conducted with individuals familiar with the issue, including representatives of scientific and professional societies and associations of academic institutions, and faculty members and administrators from a variety of educational institutions. To determine whether equipment problems were affecting the quality of preparation for future careers of science and engineering bachelor's degree recipients, interviews were conducted with deans of graduate schools and industry representatives. Finally, officials responsible for Federal Government programs in undergraduate science education were interviewed for their perspectives on the policy issues.

In the course of the interviews, OTA concentrated on the following questions:

- To what degree is undergraduate instructional equipment obsolete or deficient? How do these deficiencies affect the quality of instruction in science and engineering in the Nation's colleges and universities?
- What are the causes of equipment deficiencies?
- Which fields of study have the most serious problems with obsolete equipment?
- Which types of equipment are most deficient?
- Which types of institutions are most in need of improved equipment?

- What are the effects of equipment deficiencies on the preparedness of science and engineering B.S. degree recipients for future careers?

- What solutions are available to remedy the deficiencies in scientific equipment for undergraduates?

This background paper presents the results of those interviews. It is divided into five sections. Section I discusses the magnitude, impact, and causes of the problem as perceived by educators and scientists. It attempts to answer the first two questions listed above. Section II breaks down the equipment problem by major field and type, with chemistry and engineering given the greatest attention as the fields with the most serious problems. Section 111 discusses the equipment needs of different kinds of institutions, with an emphasis on small liberal arts colleges and junior colleges. Section IV describes the effects of equipment deficiencies on the preparedness of science and engineering B.S. recipients from the point of view of graduate school deans and industrial employers. Finally, section V reviews current Federal programs for undergraduate instructional equipment and lists some possible methods and options for increasing the supply.

I. THE MAGNITUDE, IMPACT, AND CAUSES OF THE UNDERGRADUATE INSTRUCTIONAL EQUIPMENT PROBLEM: VIEWS OF EDUCATORS AND SCIENTISTS

Scientific and engineering equipment is required in undergraduate education for two different purposes: to teach the phenomena of physical principles, and to demonstrate the capability and power of modern instrumentation for problem solving. There appears to be consensus among educators and scientists about the deficiency of instrumentation and equipment for undergraduate science and engineering education. However, there is no consensus on the implications of the deficiencies, the extent to which the deficiencies affect the quality of graduates, and means for alleviating concerns.

The current concern over the state of scientific equipment in academia reflects several important scientific developments over the past two decades. Advances in computers and microprocessors have affected every aspect of the scientific laboratory, making it possible to collect and analyze data in a matter of minutes; an analysis that might previously have taken weeks. The speed and precision contributed by computers to scientific observation have, some educators say, permitted undergraduates to leapfrog through the curriculum at an accelerated pace compared to the previous generation. The educational value or effectiveness of this leapfrogging is not yet documented. Other advances in instruments, not related to computers, have permitted scientists to analyze weaker spectra and smaller particles of matter. The use of improved Nuclear Magnetic Resonance instruments in chemistry is one example. The improved analytical range of this instrument has permitted the field to move forward in its understanding of matter. In many fields, students at the introductory level are required to learn information that was not available with the instruments of a previous generation and to understand how the modern instruments make such information available.

Most educators look back upon the decade following the launch of the Soviet satellite Sputnik in 1957 as the last period of serious national concern for science education. In the 1960s, a vast flow of Federal funding permitted universities and colleges to equip their scientific laboratories with modern instruments. During this same period, a variety of Federal programs were established to improve the quality of undergraduate science courses through seminars for teachers, financing equipment grants, and assisting with curriculum development.

According to a 1985 report by the Association of American Universities, the National Association of State Universities and Land-Grant Colleges, and the Council on Governmental Relations, Federal support for academic research, including equipment, increased by an average of 15.7 percent per year from 1953 to 1967. From 1968 to 1983, Federal funding increased at an annual average of 1.6 percent.[1] In addition, two programs that provided funds for improving facilities, the Graduate Research Laboratory Program and the Institutional Grants for Science Program, were eliminated in the 1970s. This has caused financial difficulties for research institutions. While these programs were aimed at research activities, they had a "trickle down" effect of improving all university facilities and freeing up equipment for undergraduate use. Some analysts believe that research support at universities has been sustained at the cost of cutbacks in undergraduate equipment. The result, academics say, is equipment that is old, in disrepair, or obsolete. A number of professors told OTA that alumni who visit their college laboratories frequently express surprise that the equipment is unchanged since their years in school. In many cases, the equipment in use is older than the students.

Faculty members from a wide variety of institutions stated that their equipment is either obsolete or in disrepair owing to a combination of events that have occurred over the past 15 to 20 years:

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1. Association of American Universities, National Association of State Universities and Land-Grant Colleges, Council on Governmental Relations, Financing and Managing University Research Equipment (Washington, DC: 1985), p. 15.

- inflation;
- escalating equipment costs (rising at a rate faster than general inflation);
- the increasing sophistication of scientific and engineering equipment over the past decade;
- breakthroughs in both equipment and scientific fields;
- a rapid pace of technological change in equipment, particularly computers;
- an increasingly sophisticated curriculum, especially for junior and senior level science majors;
- declining Federal funds for undergraduate science education;
- tight budgets at State funded institutions, because of State fiscal policies;
- an increase in student enrollments in engineering schools over the past decade, which has placed pressure on laboratories designed for smaller numbers of students; and
- a decrease in enrollment at small private colleges with corresponding budget strains.

In addition, faculty and administrators frequently commented that during budget crises, equipment repairs or replacements were the first items to be deferred. Faculty salaries have been, and at many schools remain, the first priority in terms of budget needs. One engineering dean stated that he expected to divert money from his equipment fund to boost salary offers in his effort to attract new faculty members. At the same time, he called the engineering college's equipment budget inadequate: it represents about half of the total amount that his department chairmen were requesting for new instruments.

A general concern is that new science and engineering graduates have spent much less time in the laboratory during the course of their education than was common a decade ago. Some industry employers stated that their new employees appeared to have a more theoretical and less hands-on education than the employers had expected. Thus, they require more on-the-job training.

Several educators report that lab requirements and offerings are being reduced because the equipment requirements are so expensive. Some small colleges are dropping certain majors — such as physics — because of the high cost of equipment.[2] However, there is disagreement among academics as to whether the trend toward reduced laboratory experience was caused by the rising cost of equipment or by other factors.

Bassam Z. Shakhashiri, Assistant Director for Science and Engineering Education with the National Science Foundation, stated that many universities have dropped the lab component of their first semester introductory science courses because of a lack of funds for equipment, chemicals, and staff. He said that many universities justify this trendon the grounds that it will give students a theoretical basis in the first semester, to be followed by a lab course in the second semester. In reality, he contended, this approach weeds out many talented students by the end of the first semester, because they have not experienced the challenge and excitement of the discipline in its laboratory setting. The trend toward eliminating lab experience, Shakhashiri said, borders on the criminal.[3]

Many academics said that the decline in laboratory offerings could also be attributed to the lack of credit toward tenure given to young faculty for participating in laboratory teaching, compared to research and paper-writing. This is unsung work,[v] noted George Dieter, Dean of the University of Maryland Engineering College. Others attributed the reduced laboratory experience to declining interest on the part of students. According to Massachusetts Institute of Technology (MIT) physics professor John King, it was student dislike, together with lack of faculty interest, that caused the demise of the lab requirements for the introductory physics courses at MIT. Over a 20-year period, MIT experimented with a variety of lab courses that would hold greater interest for the student. Today, each student is required to take a projectlab~ in which the student defines a question and develops an experiment. Unlike the original

2. Violet Meek, Council of Independent Colleges, Washington, DC, interview, 1985.
3. All unreferenced quotations are taken from interviews conducted by an OTA contractor during 1985. See Appendix A for a complete list of interviewees.

introductory physics requirement, however, the student may choose from several science departments for location of the project. King expressed concern that students are displaying a “white collar trend away from experiments. [4]

4. John King, Massachusetts Institute of Technology, interview 1985.

II. DETERMINING NEED: VARIATIONS BETWEEN FIELDS

Virtually no field of research is untouched by the potential of new instrumentation or computing devices to accelerate the acquisition and analysis of data. The knowledge available to the undergraduate in science or engineering may have been derived recently from research employing state-of-the-art equipment. [t is essential, therefore, for the undergraduate to be able to understand the fundamental principles underlying the instrumentation. While developments in research technology have affected all fields in science and engineering, the fields mentioned most frequently in terms of advances in instrumentation were chemistry and engineering. Biology, physics, and the social and behavioral sciences were also mentioned, though less frequently than chemistry and engineering. Each field is discussed in this section.

Engineering

From the educators' and often from the engineering profession's point of view, engineering education has been affected by an unfortunate timing of factors — enrollment trends, advances in technology, and cuts in state financial support — which has often placed needed equipment beyond the range of the typical college budget. Enrollments at engineering schools have more than doubled since 1973.[5] Thus, the quantity of laboratory equipment needed has increased as well. According to the National Society of Professional Engineers (NSPE), engineering schools have not kept pace with the necessary increase in the amount of equipment.[6] Between 1971 and 1982, B.S. engineering degrees awarded increased by 60 percent. By contrast, the number of

5. W. Edward Lear, American Society for Engineering Education, Washington, DC, interview, 1985.
6. National Society of Professional Engineers, Engineering Education Problems: The Laboratory Equipment Factor (Alexandria, VA: September 1982), p.3.

Laboratory “student stations” increased by onIy 9 percent.

Increased enrollments have stressed the equipment budgets of colleges and universities. But such stresses are not new. In the 1960s, enrollment in engineering schools rose dramatically. What is different today is an ongoing revolution in the design and development of equipment and fewer programs of financial assistance. This revolution, which has been brought about by the ever increasing capabilities of microprocessors, has made it even more difficult for schools to meet the demands for more, newer, and better equipment. Designers of this equipment believe that important discoveries are being made in the fields of computer science and electronics every 18 months. Not only have these advances placed additional stresses on equipment budgets, but they have also increased the course requirements for students in many subdisciplines of engineering, including electrical engineering, mechanical engineering, computer engineering, materials science engineering, and chemical engineering.

While enrollments and the rate of technological innovation have increased, state support for engineering schools has decreased. Since 60 to 70 percent of engineering schools are supported by state appropriations,[7] state support is a major issue. The decline in state sources of financial support began in the early 1970s. In the last 2 to 5 years, however, several state legislatures have increased funding for engineering equipment support, often because of concern that industries will be attracted to other states with more up-to-date graduates.

There is evidence to suggest that this concern is well founded. According to the NSPE study cited above, some professional engineers contend that schools are not keeping up with modern technology:

> Continuing obsolescence of laboratory equipment and instruments has placed many schools in the position of not being representative of modern professional practice . . . Rapid evolution of

7. Lear, op. cit.

> such fields as robotics, microelectronics, computer-aided design, optics, spectrographic, electron microscopy, computer-graphics, etc., has left the universities in a teaching mode far behind current professional practice. Students are not being adequately prepared to work with confidence in many areas of engineering.

W. Edward Lear, Executive Director of the American Society for Engineering Education, has suggested one reason why engineering schools are unabIe to keep pace with technological deveIopments: universities historically have spent a smaller proportion of funds to update equipment than industry. Lear estimates that schools spend 3 to 5 percent of the book value of their equipment on new purchases annualIy while industry spends 10 percent of the book value of its equipment.

It is important to note that there is no agreement about the actual extent of obsolete equipment, nor is there agreement about the cost of modernization. Various studies have used different methodologies to derive appropriate cost figures. For example, the NSPE study attempts to quantify the magnitude of the equipment problem through a survey of 26 engineering schools representative of different size enrollments and of public and private institutions. It concludes that if schools were to restore their laboratories in 1981 to the relatively up-to-date status they achieved in 1971, $1.2 billion would be required for the 250 accredited engineering schools. If, in addition, increased equipment needs caused by student enrollment growth are accounted for, the total equipment shortfall would be on the order of $2 billion. The survey found that equipment needs are 'remarkably consistent between the various groups˜representing public, private, small, and large schools. They also found that an annual expenditure on laboratory equipment of $400 per student — or of $2,000 per B.S. degree awarded — could have prevented this decline in the quality of laboratory equipment.

As a result of this decline, engineering universities are facing difficulties in receiving desired levels of accreditation. 'Recent comments by the Accreditation Board for Engineering and Technology officials tend to indicate that nearly half of

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8. National Society of Professional Engineers, op. cit., p. 32.

accreditation actions in recent years are for less than the maximum 6-year cycle . . . and the primary factor is the deteriorating condition of the engineering laboratories," according to the NSPE report.[9] A 1984 report issued by the American Electronics Association (AEA) reports that the Accreditation Board found that 87 of the Nation's 240 engineering programs had 'unsatisfactory" instructional labs in 1982. Only 8 of the 240 received an 'excellent" or 'outstanding" rating.[10]

In a 1984 AEA survey of electrical engineering department heads, 39 percent of the respondents indicated that they currently have instructional equipment that is not usable. Thirty-one percent said they turned down offers of equipment donations because they lack service and repair monies. Respondents indicated they needed, on average, an additional $21,000 over the budgeted amount for equipment at their department (AEA Status Report).[11]

Interviews with Engineering Deans

In interviews with OTA, educators representing both State and private schools agreed on several major points:

- The field of engineering is undergoing an equipment revolution primarily because of computers.
- Schools are having an extremely difficult time finding financial resources to pay for new equipment.
- The cost of equipment is widening the gap in the quality of education offered by a handful of prestigious schools and the remaining engineering schools.

The MIT's and the Stanfords can eventually afford to buy all this. The majority of

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9. National Society of Professional Engineers, op. cit., p. 4.
10. Pat Hill Hubbard and Kay Storm, AEA Status Report on Engineering and Technical Education (Palo Alto, CA: American Electronics Association, 1984), p. 19.
11. op. cit., p. 20.

engineers aren't educated there. We need a wide-scale diffusion [of equipment]," said Fred Landis, Professor of Mechanical Engineering and former dean at the College of Engineering, University of Wisconsin at Milwaukee.

MIT's Chairman of the Electrical Engineering Department, Joel Moses, confirms this view. "We are doing a pretty good job because of corporate gifts . . . . If we didn't have corporate gifts, it would be a disaster." Moses credits a $50 million gift to MIT from IBM and DEC of high-performance personal computers which became the cornerstone for 'Project Athena." He noted that at the time of the gift, the companies hadan interest in promoting and testing their computers before future engineers.

Karl Willenbrock, professor of electrical engineering at Southern Methodist University (SMU), says the financial problems are intensified for a small, private schools likeSMU. 'There is no relation between the costs of modern instruments like CAD-CAM and computer graphics and the budget of a small university for equipment, typically $50,000 per year . . . . This trend distorts engineering education. Schools now teach theoretical courses because they don't have the equipment to teach lab courses.~

Engineering faculty mentioned the following equipment most frequently as that which is needed most, but is least affordable:

- Conversion of laboratory equipment from analog to digital;
- computer-aided design (CAD) costing from about $150,000 to several million dollars;
- robotics equipment ($10,000 to $50,000 for a simple arm);
- powerful personal computers;
- oscilloscopes; and
- chemical processing equipment.

CHEMISTRY

Chemistry was mentioned frequently by both faculty and industry as one of the disciplines with the most rapid advances in instrumentation. An American Chemical Society (ACS) report reflects the concern within the profession that the increasing cost of chemistry equipment is leading to reduced laboratory training for chemists, and ultimately to a poor education:

> There is widespread concern that both the quantity and quality of laboratory experience in baccalaureate degree programs is decreasing. The requirements for formal laboratory work have always been less in the United States than in other industrialized nations, but increasing costs of modernization, upgrading or even sustenance of present levels of quality generate pressures which are resulting in even less favorabIe comparisons than before. Many students awarded bachelor's degrees in chemistry have very limited experience with modern laboratory techniques and even less experience in the design, formulation, conduct and analysis of experiments . . . . As the content of the chemistry curriculum has become more theoretical, more student time is spent in the classroom and in the pursuit of solutions to formal problems and less in the laboratory learning and perfecting those techniques which establish and maintain the real contact of a chemist with the material world. Students develop little feeling for the behavior of matter— which, ultimately, is what chemistry is all about.

The report goes on to criticize computer simulation of experiments as another force driving students further away from the actual laboratory experience that would help them to comprehend natural phenomena. The report states that the escalation in the cost of laboratory equipment that has occurred during the past 10 to 15 years 'threatens to wipe out earlier gains made by educators who brought more sophisticated instruments into the student laboratory.

ACS attempted to quantify the instrumentation problem in their report:

1) The mean age of all chemistry instruments at small, primarily undergraduate schools, is 8.9 years. The seven most commonly used instruments are over 10 years old. The report notes that, by today's

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12. American Chemical Society, Tomorrow — The Report of the Task Force for the Study of Chemistry Education in the United States (Washington, DC: October 1984), p.42.

standards, such equipment is “too old. ” A widely held estimate for the optimum useful life of a typical research instrument is about 7 or 8 years. After that, instruments need to be repaired more often or replaced because they have become obsolete. For example, over the last decade, microprocessors have been incorporated into spectrometers and chromatography, the “cornerstones of chemical instrumentation, ” to a high degree. It is now possible with Fourier transform data reduction methods to obtain spectra of very weak signals and to reduce the time required to make measurements from several hours to a few minutes. In some cases, the evolution of existing technologies has rendered existing equipment outdated. An example is mass spectrometry, where “new sample handling systems have been developed to extend the range of compounds that can be studied and new ion source have made it possible to study larger molecules than ever before. ”

2) The cost of equipping all 470 ACS-accredited small schools (primarily undergraduate) with needed equipment is estimated at $65.6 million. This figure is extrapolated from the cost estimates for instrumentation needs of 66 chemistry depart merits at small schools, which came to a total of $9.2 million.

3) Instrument maintenance budgets reported by responding departments were low in comparison to what are believed to be adequate budgets. Trained maintenance technicians are “all but nonexistent” at small departments, severe problem,” says the report, in view of the age of equipment.[15]

ACS received responses from 32 “major” and 71 “smaller” chemistry departments.[16] A major department is one in an institution in the top 100 in total R&D expenditures in chemistry, according to the National Science Foundation (NSF). “Smaller” departments are defined as those not in the top 100. While the latter category includes some departments with Ph.D. programs, these schools generally emphasized instruction more than the major departments. Smaller chemistry departments, according to the ACS report, plan to devote 69 percent of newly acquired equipment to the combined purposes of undergraduate instruction and research training, 22 percent to research training only, and 9 percent to undergraduate instruction only.

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13. American Chemical Society, Joint Task Force of the Committee on Science, and Committee on Chemistry and Public Affairs, Instrumentation Needs of Academic Departments of Chemistry, A Survey Study (Washington, DC: April 1984), p. 11-13.
14. Ibid., p. 18.
15. Ibid., p. 11.
16. Ibid., p. 2.

When ACS asked the schools to list their needs in research and instructional equipment, seven instruments were mentioned most frequently. Schools were asked to exclude computers and equipment that would cost less than $5,000 at today's prices from their list of equipment needs. The instruments listed below are consistent with the needs identified in OTA's interviews of undergraduate faculty. The list is identical, with the exception of number 7, with the equipment requested most frequently in chemistry grant proposals to NSF's College Science Instrumentation Program.[17]

1. Ultraviolet-Visible Spectrophotometer
2. Gas Chromatography
3. Nuclear Magnetic Resonance Spectrometer (NMR)
4. Infrared Spectrophotometer
5. Mass Spectrometer
6. Liquid Chromatograph
7. Atomic Absorption Spectrophotometer

In OTA interviews, chemistry department faculty mentioned NMR's most frequently as the instrument they need the most, but can afford the least. The cost of this instrument for undergraduate use ranges from $40,000, for the 'least expensive one" according to a small, private college representative,[18] to $200,000 for an NMR that could also be used for research.[19] Yet faculty members believe this cost can be justified because the use of NMR has changed the substance of knowledge in chemistry.

These faculty remember when NMR was a research instrument only one generation ago, when they were graduate students. Then, the instrument was less reliable, more difficult and more time-consuming to use than today's NMR. Now, 'it can deal with

17. Chemical and Engineering News, "NSF Sums Up First Year of Instrumentation Program/f vol. 63, Sept. 30, 1985, p. 25.
18. Julia Jacobsen, Association of Affiliated College and University offices, Washington, DC, interview, 1985.
19. Marshall Cronyn, Reed College, Portland, OR, interview, 1985.

nuclei that precursor instruments could not have touched," says Violet Meek, a chemist who now represents a group of about 300 small, private colleges in the Council of Independent Colleges. Science students beyond first-year chemistry are expected to be familiar with NMR's, Meek says.

Since most undergraduate chemistry departments can afford only one NMR, at best, hands-on experience is necessarily limited. Schools described a variety of ways in which the instrument would be used. In some cases, students would observe, rather than manipulate, the instrument to learn its purpose. In other cases, students would use the NMR in the junior or senior year while working with faculty on research projects.

Simulation of instruments (not experiments) through the use of personal computers may partially resolve the problem of the lack of hands-on experience. At the University of Wisconsin, Madison, for example, chemists are effectively simulating the operation of NMR machines on personal computers. This simulation uses a library of spectra of actual materials. The software is used to train students, prior to use of the actual machines, in order to make the process more efficient and the equipment more available.[20]

Because of the improved speed and reliability of the new generation of equipment, such as gas chromatography and NMR's, faculty contend students are now able to spend more time concentrating on the purpose of the equipment and less on the drudgery of collecting data or fine-tuning the instruments. As a result, science faculty say, undergraduates today are absorbing material that would have been limited to graduate students a generation ago.

Computerized Equipment

The computerization of laboratory equipment has advanced the chemistry

20. Robert L. Clodius, President, National Association of State Universities and Land-GrantColleges, personal communication, 1985.

curriculum. For example, Meek believes chemistry students should have experience with a digital read-out version of a gas chromatography instead of with the strip chart recorder of the previous generation's gas chromatography. She contends that the student who works in industry who has had experience with digital-generation equipment will realize that data can be obtained more quickly. This affects how a professional scientist will set up an experiment and what data he or she can realistically expect to find.

Computers are frequently used as a hardware interface to join together two instruments to form a single integrated unit. According to the American Chemical Society, interfacing a gas chromatography to a mass spectrometer is now a widespread practice.[21] This permits the identification of compounds present in such extremely low quantities that they were previously impossible to analyze.

The interface of computers with equipment has affected all disciplines of science. According to Robert Watson, head of NSF'S College Science Instrumentation Program (CSIP), the single most common objective in CSIP grant proposals is the interface with computers of scientific instrumentation, not necessarily the purchase of a computer se. Watson notes that such computers are used as an adjunct to instruments already in existence. Usually, Watson says, "there is a scientific instrument to do this, but the computer greatly enhances this ability. "

BIOLOGY

The biological sciences have traditionally required a wide range of laboratory equipment for instructional purposes. Today's basic biology laboratory should be equipped with the following: one light microscope per student (at a cost of $1,000 to $7,000 for a binocular microscope), several balances (as high as 6 to 8 per lab at a cost of

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21. American Chemical Society, Instrumentation Needs of Academic Departments of Chemistry, op. cit.

$2,500 a piece), centrifuges (4 to 5 for one course at $30,000 to $50,000 each), expensive chemicals and glassware, autoclaves, incubation equipment, refrigerators, and all of the brick and mortar requirements not restricted to bench tests such as floor space; head room; water, air and gas lines; power sources; and ventilation. While many colleges and universities already have these facilities and instruments on hand, they are often outdated or in disrepair due to heavy and continual use.

Rita Colwell, Vice President for Academic Affairs and Professor of Microbiology at the University of Maryland, describes the typical situation in an undergraduate microbiology class. There may be as many as 150 students in the introductory course. The instructor must borrow equipment from the graduate department and clean out the entire departmental supply of pH meters for a l-day laboratory session. (Often other research has to stop for a day.) Finally, the equipment may be broken or may need to be recalibrated when it is returned to the research laboratory.

According to Colwell, the cost of teaching a student in virology has more than doubled from $1,000 per student in 1976 to $2,500 per student today. She says that between 1972 and 1983, the university's budget for purchasing scientific equipment was extremely tight. "For a period, we couldn't afford to buy supplies such as tissue cultures and petri dishes — and we cut out labs. Now, as a result, we are graduating students in microbiology, with only two laboratory courses, to work in hospitals and food laboratories (as technicians). They don't know how to use a centrifuge or a spectrophotometer."

Colwell said a biology student should have the opportunity to do experiments in an introductory course that may require four to five instruments per course at a cost of $30,000 to 50,000 each. She also contends that upper level and honors students should have the opportunity to work on an electron microscope as an apprentice to a researcher. Electron microscopes range in price from $100,000 to $200,000 and were most frequently mentioned as the piece of equipment most needed by biology depart ments. The need is one per department.

“You cannot train students in microscopy without [electron microscopes],” Colwell believes. The University of Maryland, Department of Microbiology, only recently received its new electron microscope through a Defense Department research grant. Now, Colwell says, undergraduates can view microorganisms with the electron microscope in a cytology course but are not permitted to manipulate it because the instrument is too delicate.

Other equipment needs were cited in connection with the fields of biotechnology and recombinant DNA research. Biology has become more molecular and more chemical in its orientation ever since the DNA revolution. One way that the change in the field is filtering down to undergraduates is the increasing introduction of biochemistry courses for undergraduates. Demand for this course has increased both as a result of scientific discoveries and of the burgeoning job market in the biotechnology industry for those with undergraduate degrees only.[22] As a result of the discoveries and the changes in curriculum, the kind of sophisticated instrumentation used in chemistry is now more frequently used in biological research. Colleges stated that NMR’s and spectrophotometers are now being used both by undergraduate biology and chemistry majors.

In some cases, colleges still need to equip an entire lab for biotechnology work. If built from scratch, establishing a biotechnology laboratory that would serve 10 to 15 students can cost $200,000, but colleges often have in their inventory some of the basic instruments that are also common to other biology courses. The following types of equipment are needed to set up an instructional biochemistry laboratory, according to Dale Edmondson, associate professor of biochemistry at Emory University School of Medicine in Atlanta, Georgia, and Chairman of the Education Committee for the American Societ of Biological Chemists:

22. Dale Edmondson, Emory University School of Medicine, Atlanta, GA, interview, 1985.

- an ultra centrifuge
- gel electrophoresis;
- chemicals;
- sophisticated camera to photograph cells;
- mass spectrophotometer;
- pH meters;
- cold cabinets;
- autoclave (usually in a biology lab already); and
- incubation meters (usually on hand already).

PHYSICS

In this field, the list of high-cost equipment mentioned by educators as most needed includes:

- Nuclear Magnetic Resonance Spectrometers;
- computers, both interfaced to laboratory equipment and personal computers for analysis;
- oscilloscopes; and
- in a few cases, lasers, for junior and senior physics majors.

The need for the technological capability to interface microprocessor equipment to laboratory data-collection equipment and the conversion of analog equipment to digital were cited most often. However, there were strong disagreements about the necessity of the equipment conversion. While many physics professors felt pressure to convert the majority of equipment to digital read-out, some insisted that the major principles could be taught with more traditional equipment.

John King, physics professor at MIT, asserted, “We will teach them what they need to know if it (equipment) is maintained well and doesn't get 40 years behind." In his view, "no more than 20 percent" of the laboratory equipment needs to be computerized to give students a grasp of how such equipment is operated. "To do an experiment, observing is important. The computer bypasses it."

Other physics professors said it was important to have a happy medium: teaching students the principles on pre-computer analog equipment, but teaching them to be familiar with computer-supported equipment and the capabilities for acceleration of data analysis as well.

Oberlin physics professor Robert C. Hilborn was emphatic about the benefits of the computer for physics. "It has revolutionized how people think about data," he says. Because of the speed of data collection, Hilborn says, "you can think about doing more sophisticated experiments that would have taken endless time to do before. You can let the student do experiments that were not feasible before."

Aside from cutting edge research equipment, Hilborn says, there have been "no striking technological breakthroughs" in physics that have affected the education of undergraduates as NMR's have affected chemistry. As for future advances, Hilborn believes today's oscilloscopes and electronic instrumentation are at a relatively stable point in their abilities, compared to research equipment. Once purchased, it will be 5 to 10 years before there is a need to buy a new version of a recent oscilloscope or personal computer for undergraduate purposes, Hilborn predicts.

One use of computers could lead to cheaper instrumentation. Reed College, for example, uses an Apple personal computer to simulate the face of an oscilloscope on the screen for student laboratories. This eliminates the need to purchase an oscilloscope for every student, according to Reed College Vice President and Provost Marshall Cronyn. According to Professor Hilborn, computers can also be used in introductory physics courses to make the subject 'more exciting˜ for students who are not physics majors.

III. DIFFERENCES IN EQUIPMENT PROBLEMS BY TYPE OF SCHOOL

Interviews revealed some differences in equipment needs between 4-year colleges, universities, and junior colleges. The equipment problems of the different types of academic institution are summarized below.

FOUR-YEAR COLLEGES

As many as 150 colleges consider themselves to be "research colleges," judging by attendance at a recent conference on the subject of undergraduate research.[23] Recently, these schools have been the most vocal discussants of the equipment problems in scientific fields and the need for Federal support. The president of Oberlin College recently proposed that the National Science Foundation recognize the 48 leading research colleges as a distinct subset of schools worthy of special Federal support in the sciences.

Research colleges say the importance of laboratory research for students has increased while the funds that are available to provide that experience have decreased. At these schools, faculty are encouraged to do research that involves students. Because the faculty members are aware of new trends in science, they demand up-to-date equipment for their research and their students. Thus, many professors at research colleges believe that their students may have more opportunities to work on research-grade equipment than at universities, where such instruments are often reserved for graduate students.

These opportunities disappear if research colleges lack the money to purchase new equipment. These colleges believe that their efforts to obtain equipment have been

23. Chemical and Engineering News, 'Undergraduate Research Gaining a Higher Profile," vol. 63, Aug. 19, 1985, p. 17.

hampered by the small number of Federal programs available for undergraduate education. Faculty at research colleges often mention specific pieces of equipment purchased with the aid of Federal programs before 1981, when money was available. Now, however, research colleges have to compete with universities for strictly research grants, which often fund equipment purchases. The colleges say they do poorly in this competition.[24] The lack of federal funds has placed additional strains on the research colleges' budgets, which have shrunk considerably since the "baby bust" began and enrollments declined.

While elite colleges complain about the struggle to obtain equipment, they realize that they are in better shape than less well-known colleges. Smaller, less prestigious colleges appear to have greater difficulty in meeting equipment needs than research colleges. For exarnple, several small schools that belong to the Council of Independent Colleges report dropping majors in physics and computer sciences because of expensive equipment requirements.[25] The emerging field of biochemistry at the college 1evel offers one example of the contrast between research colleges and their smaller compatriots. Beloit College, one of the research colleges, was among the first to setup a biochemistry program 8 years ago. At the less well-known Monmouth College, in Monmouth, Illinois, the three-person biology department offers no such program and is not equipped or staffed to do so.

UNIVERSITIES

Depending on the State, public universities have generally suffered tight budgets in recent years as a result of fiscal conservatism at the State level combined with declining

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24. Ibid. This trend maybe reversing, according to recent National Science Foundation (NSF) figures. In fiscal year 1984, about 27 percent of the undergraduate research proposals submitted to the NSF were funded, in line with overall funding ratios in most NSF support programs.
25. Meek, op. cit.

enrollments. However, some State universities are reviving their laboratories as a result of recent State appropriations aimed at solving the problem.[26]

Universities differ over whether the existence of a strong research-oriented graduate department is beneficial to undergraduates. While some faculty said that the presence of a graduate research program made more equipment available to undergraduates — particularly honors-level juniors and seniors — others said that graduate departments often closed their doors to undergraduates. Several university faculty suggested that research programs can actually be a liability for the undergraduate program because Federal matching research grants put increased pressure on the equipment budget shared by undergraduate and graduate departments.

The most prestigious private universities, such as the Massachusetts Institute of Technology, have benefited from large corporate donations to update their equipment. Even in these cases, however, faculty from such universities express concern about keeping up with changes in their fields.

For less prestigious large universities, needs for laboratory equipment appear to be similar to those of 4-year colleges. Personal computers, however, appear to be less of a financial problem than for small colleges, because of the promotional discounts and donations made by computer companies to larger institutions.[27]

JUNIOR COLLEGES

Junior colleges need two kinds of equipment: equipment for vocational education in increasingly technical fields such as auto repair, robotics, numerical control, and computer programming; as well as the same equipment needed at other sch 001s for instruction in biology, physics, and chemistry classes.

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26. Michael Heyman, Chancellor, University of California at Berkeley, Berke ey, CA, interview, 1985.
27. Jules Lapidus, Council of Graduate Schools, Washington, DC, interview, 1985.

In my view, there are severe equipment problems," states Bernard J. Luskin Executive Vice President of the American Association of Community and Junior Colleges. Although the Association has no data on the age of equipment, it is assumed that most scientific and vocational equipment in use was purchased when the junior colleges opened.

Because junior colleges tend to train technicians directly for jobs in local industry, local companies may be more disposed to donate equipment to 2-year colleges than to their 4-year neighbors. Close company ties can also put strong pressures on 2-year colleges. Snow College, a 2-year college in Ephraim, Utah, with an enrollment of 1,400, recently acquired an IBM mainframe computer at the insistence of nearby employers. "Without that, we had companies saying 'we're not interested in hiring your programmers',~ according to Snow Col ege President Steve Bennion. In addition, some junior colleges may have the advan' age of local taxing power over nearby State universities which have been affected by the fiscal constraints placed on them by State legislatures.[28]

28. Fred Landis, University of Wisconsin at Milwaukee, interview, 1985.

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." 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" 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."

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

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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

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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." 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.

V. SCIENCE EQUIPMENT FOR UNDERGRADUATES: PROGRAMS AND OPTIONS

One Federal program is aimed specifically at providing grants for instructional science equipment at the undergraduate level. This is the College Science Instrumentation Program (CSIP) administered by the National Science Foundation. CSIP received an appropriation of $5 million in fiscal year 1985, its first year of operation. The same level of funding was appropriated for fiscal year 1986. The proposed level of funding for fiscal year 1987 is $7.5 million. CSIP, which was initiated by Congress, is similar to an earlier program, the Instructional Scientific Equipment Program (ISEP), which was in existence for 20 years until it was eliminated in 1981.*

Only those 4-year colleges without graduate programs are eligible for CSIP grants, which must be matched on a '50-50' basis by other sources. ISEP was open to universities and 2-year colleges as well. In 1985, CSIP funded about 17 percent of the 1,348 proposals submitted.[44] This funding rate is similar to the 17.5 percent of the proposals funded by ISEP in 1981, the last year of that program's operation.

The number of proposals submitted for CSIP grants is surprisingly similar to the level submitted to its predecessor program in 1981 (1,348 for CSIP compared to 1,399 for ISEP). While this suggests that the need for equipment has remained fairly constant over the years, it is important to remember that a smaller number of schools are eligible for CSIP than its predecessor program. Also, some educational associations suggest,[45] the number of proposals can be expected to be greater in subsequent years as this new, revived program becomes better known in the academic community.

While CSIP is the only Federal program aimed specifically at undergraduate

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* Between 1981 and 1984, the National Science Foundation (NSF) had no equipment grant program for undergraduate science equipment. The Instructional Scientific Equipment Program (ISEP) was one of many education programs ended when the NSF Science and Engineering Education branch was closed in 1981.

44. Chemical and Engineering News, "NSF Sums Up First Year of Instrumentation Program/' op. cit, p. 25.

45. Ida Wallace, Independent Colleges Office, Washington, DC, interview, 1985.

equipment, other NSF grant programs may provide equipment to undergraduates institution as part of research grants. According to the Office of Management and Budget,[46] NSF spent a total of $88 million on undergraduate equipment between 1982 and 1985, compared to $100 million between 1952 and 1982. The totals include CSIP grants, support for undergraduate faculty research proposals submitted directly to NSF's disciplinary research programs, and proposals submitted through the Research in Undergraduate Institutions program.

Most of the members of the academic and industrial community interviewed by OTA agreed that it would take a combined effort by the Federal and state governments, academia, and industry to update the laboratory equipment that is used to educate undergraduate science and engineering majors.

The undergraduate institutions and the Reagan Administration differ vigorously on the role that the Federal Government should play in helping to bring equipment up-to-date. The Administration considers undergraduate education to be a State and institutional responsibility, not a Federal one. Colleges answer that: l) since the 1950s, NSF has had numerous programs aimed at undergraduate science; and 2) the quality of undergraduates eventually affects the research done by the Nation's scientists. The Federal Government, in response to complaints by schools, points to industry donations as a source of additional support. But both academics and industry representatives say that these donations are relatively small compared to the scope of the equipment problem.

In the belief that there is a clear national interest in helping the Nation's scientists to advance the frontiers of research, many Administrations have placed the majority of Federal science support into research and graduate schools. This policy assumes that undergraduates who seek science careers on the frontiers of their field will somehow manage until they reach graduate schools, where the funding for science is concentrated. Undergraduate education has been seen as a State, local, and private

46. Loweth, op. cit.

responsibility. Undergraduate institutions must weigh the increasing cost of equipment to prepare students for graduate work or employment in science and engineering against declining enrollment and budgetary pressures.

John Wright of the University of Alabama, in his testimony on the University Research Facilities Revitalization Act of 1985, before the House Committee on Science and Technology, Subcommittee on Science, Research, and Technology, recognized the importance of the 4-year college in educating science students. He noted that these students go on, in high proportions, to succeed in post-graduate work, earn doctorates, and become research faculty at leading institutions.[38] This point is of primary importance to a group of 48 prestigious liberal arts colleges, the self-proclaimed research colleges, who contend that they contribute to the Nation's scientific base by producing a disproportionate number of the Nation's future researchers.[39] This group of colleges is vocal in their demand that the Federal Government support their research efforts. In some disciplines, such as engineering, the majority of students enter the profession with undergraduate degrees only. In other fields, which require graduate work as a professional entry card, the undergraduate experience remains critical for interesting students in pursuing a research career.

Where does the Federal Government draw the line on its responsibility to support education? Can the Federal Government mobilize sufficient funds to support an expanded field of educational institutions? Considering that by one study's estimate, over $2 billion would be needed just to bring everything in engineering colleges up-to-date, the needs in all scientific fields for all colleges and undergraduate departments of universities could be staggering.[40] To quote one veteran budget official, 'Part of the

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38. Statement by John Wright on the University Research Facilities Revitalization Act of 1985 before the House Committee on Science and Technology, Subcommittee on Science, Research and Technology, Oct. 22, 1985.
39. Testimony of S. Frederick Starr, President, oberlin College, before the Task Committee on Undergraduate Science and Engineering Education, the National Science Board, Sept. 26, 1985, pp. 7and 10.
40. National Society of Professional Engineers, Engineering Education Problems: The

reason for a policy against it [supporting undergraduate education] is so you don't have to face up to how much you have to do."[41] Many of the individuals interviewed OTA asserted, however, that incremental increases produce proportionate improvements in the quality of instruction.

How then can science and engineering departments finance their equipment purchases? The solution *most* commonly proposed is a combination of Federal, State, industrial, and academic support for new equipment. Since all of these sources have their own limitations and other competitors for funds, another possibility is that the increasingly expensive costs of scientific and engineering equipment will force a reduction in the number of schools or departments that teach equipment-intensive fields. The tendency of some companies to favor applicants with graduate degrees suggests that graduate schools, not undergraduate departments, will continue to be the principal location of newer technological equipment in the future. The extent to which purchases of graduate research equipment influences the needs for undergraduate instructional equipment is not clear.

Internships, through which students have a chance to use modern equipment at nearby industries, are often proposed as a solution for universities and colleges unable to replicate modern industrial equipment. 'Cooperative" programs, where students work for one or two semesters in an industrial or government laboratory, are offered for credit by many engineering and chemistry departments.

While some in academia look upon cooperative programs as an excellent supplement to the student's education in the use of equipment,[42] others are emphatic that such programs should not replace the university's obligation to stay up-to-date.[43] Objections raised to such programs include difficulties for schools not located near appropriate

Laboratory Equipment Factor (Washington, DC: September 1982), p. 6.
41. Hugh Loweth, Office of Management and Budget, Washington, DC, interview, 1985.
42. Thaddeaus C. Ichniowski, Illinois State University, Normal, IL, interview, 1985.
43. George Dieter, Universityof Maryland, College of Engineering, College Park, MD, interview, 1985.

industries and the issue of academic independence. “The university has to provide the opportunity to pursue knowledge for the sake of knowledge, ” says Rita Colwell, Vice President for Academic Affairs, University of Maryland. “If we turn into an apprentice shop for industry,” Colwell objects, “the university will not be serving that primary goal. ”

Because there is no consensus about the effects of the undergraduate equipment problem on the quality of education on scientists and engineers, there is no consensus as to the best way to proceed. As mentioned in this brief paper, options range from new Federal direct assistance to increased cooperation with industry, from active decisions as to the number and type of institutions that meet some ‘national need” criteria to simply allowing individual institutions to manage as best they can, and from defining the undergraduate years as a strictly State and local responsibility to specifying a commitment to this portion of technical training. Until these questions are resolved, it is unlikely that there will be agreement on new policy steps.

APPENDIX A

INTERVIEW LIST

David C. Allison
Professor and Chair
Biology Department
Monmouth College

Joseph Arrigo
Former Manager for Research
Process Division
Universal Oil Products

Angelo Bardessus
Associate Chairman for
Educational Affairs
Physics Department
University of Maryland

Eileen Baumgartner
Staff
Office of the
Honorable Martin Olav Sabo
U.S. House of Representatives

Steve Bennion
President
Snow College

Dr. Robert Bock
Graduate Dean
University of Wisconsin

Newman Bortnick
Research Division
Rohm and Haas Co.

Darcy Brent
Vice President for Engineering
Bayard Corp.

Robert Clodius
Director
National Association of Universities
and Land-Grant Colleges

Rita R. Colwell
Vice President for
Academic Affairs
University of Maryland

Dale Compton
Vice President for Research
Ford Motor Co.

Marshall Cronyn
Vice President and Provost
Reed College

John C. Crowley
Director
Federal Relations for Science Research
Association of America~ Universities

David Davis-Van Atta
Director of Institutional Research
Oberlin College

George Dieter
Dean of the College of
Engineering
University of Maryland

Gerald Dinneen
Corporate Vice President for
Science and Technology
Honeywell

Dan Drucker
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