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ABSTRACT

This report, presented in nine parts, contains an executive summary and recommendations, historical background, the national context, a description of physics programs in Virginia for physics majors and those in other majors, a description of students' experiences in physics programs including alumni, an explanation of distribution of faculty responsibilities, a discussion of the recruitment and retention of women and minorities as students and faculty, a description of facilities, an explanation of the costs and benefits of physics programs, and a discussion of partnerships. The executive summary contains five major recommendations that are designed to: (1) preserve the strength of the existing programs while correcting some anachronisms; (2) bring many small programs together to produce teaching and research alliances; (3) and identify special opportunities on which physics departments can focus to attain national status. The recommendations suggest that physics programs should: (1) evaluate their curricula in light of future employment opportunities; (2) form alliances with other programs in physics and related disciplines; (3) communicate more effectively; (4) correct inequities in the enrollment of women and minorities; (5) and keep track of costs and benefits more effectively. (DDR)

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A Report by the Virginia Task Force on Physics

Presented to Virginia's Colleges and Universities and the State Council of Higher Education for Virginia

July 22, 1996

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Executive Summary

The physics programs in the Commonwealth, as in the rest of the nation, are facing serious challenges, and the way they meet these challenges will have a significant effect on the technical underpinning for Virginia's economy in the next century. These challenges to the programs have been exacerbated by fiscal conditions, but their underlying origins are structural.

- Changes in the national economy have decreased traditional employment opportunities for physics graduates. Meanwhile, the increasingly diverse range of careers into which they now move or have ambitions to move require a broader range of skills than are taught in a traditional physics curriculum.

- An otherwise very attractive characteristic of Virginia's colleges and universities -- their geographic dispersion into relatively small units -- has created special problems for physics programs. Although they should play a vital role in the liberal education of all students and in providing foundational knowledge to other majors in science and engineering, they typically attract relatively few majors. But physics programs require a critical mass of faculty for excellence in research and graduate teaching, and a vibrant research program is in turn increasingly important for the "hands-on" training of undergraduates.

While various of our colleges and universities have had some isolated successes in addressing these conditions, the picture put together by the task force --- based on submitted materials, site visits, and knowledge of both Virginia and the national scene --- is troubling.

At the same time, the current state of stress also offers an opportunity for change which might not have existed otherwise. Our recommendations are designed to 1) preserve the strengths of existing programs while correcting some of their anachronisms, 2) bring the Commonwealth's many relatively small programs together into teaching and research alliances, and 3) identify special opportunities in Virginia on which physics departments can focus to attain national status in selected strategic areas.

Major Recommendation 1:

All physics programs at all levels should rigorously examine their curricula to assess the balance in the education they offer in view of the wide spectrum of employment opportunities their graduates will have in the future.

While there were notable exceptions, the task force discovered that a narrow academic orientation in physics training was the rule in the Commonwealth's colleges and universities. Baccalaureate and master's programs measure themselves almost exclusively in terms of their success in placing students in graduate school, while Ph.D. programs focused on the number of potential professors they produce. This drive to replicate academicians might once have made sense, but now it certainly does not.

In making this criticism, we are not suggesting a radical change in the fundamental character of an education in physics. Physics is one of the liberal-arts disciplines and provides students with fundamental problem-solving skills. That is why the role of the physics department in general education and in the foundational learning of students in other sciences and engineering is so critical -- the task force believes that all students, and certainly physics majors, should have a solid grounding in "problem-solving, physics style."

However, surveys of physics graduates make it abundantly clear that it is the mode of thought and not the facts *per se* which are the core strengths of a physics education. There are today few job opportunities in pure physics but myriad job opportunities for physicists. These jobs require the problem-solving skills of a physicist much more than the detailed information of a physics degree. More important in most cases, today's employment requires an appropriate mix with many other skills not traditionally taught in physics education. Many physics programs across the state currently are unintentionally short-changing their students in these nontraditional areas of training.

From this perspective, physics curricula need to add new skills to the repertoire of physics graduates that can be vital to their future career success. There is a widespread belief that courses in communication skills and business could be valuable to many students. There is also growing evidence that the hands-on and teamwork skills that can be developed in laboratory-based senior project courses or internships are crucial for the job market of today and of the future. For a long time, research projects for majors have been recognized as a significant part of the most successful undergraduate programs, even though not all programs have provided or emphasized such experiences. On the other hand, internships are not a part of the physics culture at most institutions.

The physics curriculum could also be broadened in other ways. For example, in addition to traditional academic training, some colleges and universities might have students specialize in advanced data-acquisition techniques, while others might focus on preparing them for advanced degrees in engineering, work in the business world, or careers in high-school or community-college teaching.

Major Recommendation 2:

> Physics programs across the Commonwealth should form alliances with other programs (in physics and in related disciplines) to broaden their course offerings, to create programs with more diverse foci, and to strengthen their research efforts through increased specialization and interuniversity collaboration.

The geographic dispersion and relatively small size of Virginia's colleges and universities give many advantages to their physics programs. Among these are the ability (with faculty sizes from two to over thirty) to offer the intense, one-on-one or one-on-several contact required to retain students in physics in their first and second years. Indeed, the task force found that very small departments often did an outstanding job supporting students' learning in these critical early years.

From the third undergraduate year through graduate school, the separation of the system into small, isolated units seems to have substantial disadvantages. The smaller schools have great difficulty in exposing their students to a broad range of advanced topics in the third and fourth years or in offering the opportunity for all seniors to work on research projects. Even the larger schools --- all with graduate programs --- have more complete (though for some students less supportive) undergraduate programs but have difficulty in offering a broad range of advanced graduate courses.

Even these latter departments --- while large for Virginia --- are small when compared to the best research departments in the country. When peers assess the quality of each other's programs, according to the National Research Council, size matters,[1] among other reasons because relatively small departments in the sciences have the very serious problem of being subcritical in the size of some of their key research groups. By comparison, the nation's top ten comprehensive research physics departments average about 53 faculty, almost 20 more than the largest Virginia department.

None of these problems can be realistically addressed by the current departmental units acting in isolation. In contrast, alliances between units offer solutions which at the same time avoid unnecessary duplication of teaching and research efforts. For example:

- Small undergraduate programs could offer a more diverse set of courses in upper years by using postdoctoral fellows and advanced graduate students from another institution as supplementary faculty members. These young researchers would, in addition to earning money, gain valuable teaching experience under the tutelage of some of the Commonwealth's finest teachers.

- Departments could form alliances to permit students who start their course of study at one college to complete it at another. Many physics students we talked to expressed career interests -- for instance in engineering or computer science -- that could be supported by articulation agreements like the 3+2 program

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Longwood College's physics program has with the College of Engineering at Old Dominion University. Another kind of cooperation occurs when institutions form partnerships to share courses and bring in guest speakers, such as the ones Longwood and VMI have formed with Hampden-Sydney and Washington and Lee.

- Research departments that are currently limited to offering important advanced topics only every two or three years could share the load of such courses by allowing students to take courses by two-way videoconferencing or other telecommunicated modes of delivery.

- Through cooperation and sharing of resources, smaller faculty groups could have greater impact in research. One way to do this is to focus their research interests and faculty hiring more narrowly and then rely on partner institutions for breadth in teaching their students. Another possibility is to exploit natural strengths of the other research opportunities in the Commonwealth. Among these are the Thomas Jefferson National Accelerator Facility (the "Jefferson Lab," formerly the Continuous Electron Beam Accelerator Facility or CEBAF), with its $600 million of nuclear and particle physics infrastructure and "fourth-generation" Free Electron Laser (FEL) light source, currently under construction; NASA's Langley Research Center; and the industrial laboratories of advanced-technology industries locating in Virginia. Such cooperation will also call for advanced videoconferencing facilities and enhanced opportunities for faculty and students to work together at both their universities and distant sites, as envisioned by the recently formed Virginia Physics Consortium (VPC) The VPC is a collaboration of the doctoral-granting institutions in physics, Norfolk State University, and the Jefferson Lab, whose mission is to "provide the framework and resources for coordinating the [teaching and research] activities of its members in physics and in related disciplines and technologies, especially those activities focused on the facilities for nuclear physics, particle physics, atomic-molecular-optical physics, and condensed matter physics at the [Jefferson Lab]."

Major Recommendation 3:

Physics programs should communicate and work more actively with their various constituencies, including other departments on campus, feeder high schools and community colleges, their alumni, local businesses and industry, and -- last but certainly not least -- their own students.

The task force found on its campus visits that physics faculty are typically very dedicated and hard working. But between the demands of the classroom and the laboratory, their mentoring of individual students and study groups, and their own research, the faculty often have little time or energy to spare for looking beyond their own program's boundaries, let alone the institution's walls. Nevertheless, it is vital to the continued health of Virginia's physics programs that they do so. For example:

- Physics programs need to be major players in the campus-wide general-education program, which means that they need to put time and energy into the development of physics and interdisciplinary science courses for non-majors. They also feed (and are fed by) other curricula: they need to rely on departments of mathematics, for instance, to help teach their students quantitative problem-solving skills, just as engineering schools rely on them to teach **their** majors the fundamentals of physics. The task force found that the faculty in many physics programs had not successfully bridged the gaps between them and their colleagues in other programs. Consequently, it was left to the students to leap those gaps, which they were not always able to do successfully. Moreover, too many physics departments fail to exploit alliances with other departments within their own institutions that could be useful in broadening the skills of physics majors. Mathematics, computer science, education, business, and law departments, to name a few, may have (or could arrange to have) offerings of great value to physics students. Interdisciplinary offerings might be the logical extension of such cooperation. Faculty can also cooperate across departments in exploring new educational delivery systems. There is usually a limited number of faculty on any one campus interested in these issues -- they need to be networked to provide mutual stimulation and promote efficiency.

- Physics faculty need to communicate with students in primary schools, secondary schools, and community colleges, lest the pool in which they fish dry up. A recent study done at Wellesley College found that only 4 percent of the science majors there did not think that they would major in science when they came to the college.[2] Students --especially women and minorities -- need to know well before the eighth grade that science is an interesting pursuit, since that is when they decide whether to take the mathematics and science courses that will enable them to move smoothly into a collegiate science curriculum. The teachers they have in these early grades can feed or kill that interest, depending on how knowledgeable they are about how best to reach those students. The task force was heartened by what it saw in this area: many departments have active outreach programs to the schools, both directly through lectures and demonstrations to students and indirectly through nationally and state-sponsored programs geared at updating teachers on the latest developments in research and pedagogy. Community colleges are another important source of potential physics majors, but very few senior institutions' physics departments mention efforts to ensure that their programs couple smoothly with the community-college curriculum. The task force encourages physics faculty to talk regularly both with high-school and community-college science faculty at their major feeder institutions so that students will not experience discontinuities in their education and be discouraged from pursuing the study of physics and other sciences.

- Alumni are an untapped resource on most campuses. Unfortunately very few physics departments have kept track of their undergraduate or graduate alumni. They could be used to inform, mentor, and support students in a number of ways: by serving on panels to explore with students their varied career choices and how to prepare for them, by providing internships for students, and by advising faculty on the relevance of the curriculum, for instance. We suggest that programs locate their alumni and set up homepages and alumni listserves, perhaps maintained by students in the program, as one easy way to keep in touch with and make use of their graduates.

- Local businesses and industries are another important resource that is too often overlooked. They could enrich the real-life relevancy of programs by serving on advisory committees, providing internships, and becoming employers of programs' graduates.

- In focusing on the need to communicate with constituencies outside the program, the task force does not want the faculty to overlook the most important constituency of all: their students. On each campus we visited, students were pleased with the opportunity to speak as a group about their program. Too often, they do not have that opportunity on a regular basis. This is not to say that faculty do not communicate with students individually or in small groups, but those conversations generally focus on the physics problems that are engaging their attention at the moment. Larger issues -- like the success of the curriculum or the range of non-traditional job opportunities for students -- are too rarely addressed systematically. The exiting senior surveys that some departments have instituted for purposes of assessment are promising in that regard, but the task force recommends that they be supplemented with regular town meetings at which students' concerns can be addressed.

To be able to act as a community these various ways, faculty need also to communicate with each other and with their administrations regularly and civilly. In some of the programs, the diversity of interests and time constraints limit that dialogue. But such intradepartmental and departmental/administration communication is crucial, not only because it permits programs to get their essential business done but because it models for students how groups of people can work cooperatively in a world in which few people work alone.

Major Recommendation 4:

> Virginia's women and minorities remain very underrepresented in physics programs, and more serious effort should be focused on correcting this imbalance.

While many of the root causes of the underrepresentation of women and minorities in physics programs are probably societal in origin, it has been clearly demonstrated that sustained outreach programs addressed to K-12 students can have an effect on the problem. It is also clear that poor retention rates are at least in part due to inhospitable environments in many physics programs. While white male faculty can be, and in many programs in Virginia clearly are, very welcoming to and supportive of their women and minority students, it is also useful for those students to have models of success who look like them. Yet the lone black or female faculty member is apt to feel isolated and overburdened with the responsibility of being the only such role model in the department. So an important step in increasing student diversity is to move faculty representation above a "critical mass" by actively recruiting and removing all obstacles to the retention and promotion of qualified women and minority faculty members and by creating a supportive environment for students.

Major Recommendation 5:

> Virginia's physics programs should keep better track of their costs and benefits, and they should implement the suggestions in this report through well-prepared plans with milestones coupled to external reviews reporting to the provost. The entire system of programs should then be reexamined in four years for evidence of progress along the lines recommended in this report. SCHEV should work with the Virginia Physics Consortium to set up an interim review process, including an annual meeting of program representatives, to facilitate the communication required for effective system-wide change.

The task force is convinced that physics programs that are unable to meet the needs of their students and their communities will lose their vitality and in most cases will not survive. It therefore strongly urges departments to embark on the process of critical self-examination, planning, and external review required for effective change.

In summary, the Virginia Task Force on Physics has concluded that by implementing these recommendations, existing institutional resources in Virginia could allow the Commonwealth to become a model and a more important national player in physics and its related disciplines and technologies. Given the importance of such strength for the future of Virginia, we urge the Council of Higher Education to adopt these recommendations and carefully monitor the health of this important set of programs.

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Part I: Historical Background

In 1995 the staff of the State Council of Higher Education decided to do this review of all the public undergraduate and graduate physics programs in the state, its first statewide disciplinary study since 1986. The origins of that decision reach back into the previous decade. In 1986, the Council had decided that the combination of productivity review and the newly instituted statewide assessment program was sufficient to ensure the quality of Virginia's academic degree programs. By 1995, several developments led to a reconsideration of that decision. The turbulent nineties, with massive budget cutbacks followed by restructuring and partial restoration of public funding, had required a fundamental reexamination of how the Commonwealth's colleges and universities accomplish their missions. The Council staff thought that such a reexamination was incomplete without an attempt to look at collegiate education within at least one core discipline.

This decision to do a statewide disciplinary review was strengthened by several other developments:

- In its report on the work of the Council, the Joint Legislative Audit and Review Committee had declared that the Council's productivity review process needed to be strengthened by, among other things, the review of programs "collectively by subject area."

- Second, the General Assembly's Commission on the Future of Higher Education had expressed concern about the unnecessary duplication of degree programs. This concern was later embodied in a revision to the Council's statutory responsibilities: the 1996 General Assembly asked it to consider unnecessary duplication as an issue when it reviewed the productivity of programs. The core liberal-arts disciplines pose a special set of questions in this respect: are they necessary to any college or university, however low the students numbers in them are? Is there any way to improve their attractiveness to students rather than close them?

- Finally, budget cutbacks and the General Assembly's mandate that the public colleges and universities restructure meant that on many campuses, the curriculum in general and high-cost programs in particular were already under intense scrutiny.

If the Council was going to undertake a statewide review of one of the core disciplines, physics was an obvious choice, since it embodies the all the most difficult challenges in program review. On the one hand it is a liberal-arts discipline that attempts to describe the very structures of reality, it develops in students essential problem-solving skills, and it has enormous economic-development potential in training people to work with advanced technologies. On the other, at some institutions it has had difficulty attracting students, particularly women and minority students, into its general-education courses and into the major; its graduates, like those in other core liberal-arts (and even more vocational) disciplines, have recently had difficulty finding academic, program-related employment; and it is a relatively costly program to offer.

Physics also has some strengths that other programs lack. Physics departments are often important to their institutions because of their frequently high level of sponsored research when compared to other departments. Researchers in Virginia benefit from the presence in the state of such entities as NASA Langley, IBM/Toshiba, and Motorola. The presence in the state of the Jefferson Lab (formerly CEBAF), one of the world's premier high-energy physics research facilities, was particularly important, and its willingness to co-sponsor the physics review was critical to the review's success, because of the credibility and support such co-sponsorship lent the process and its results. As well, around the Jefferson Lab has coalesced a group of researchers from all over the state. This has led to the development of the Virginia Physics Consortium, a model for cooperative efforts in research and education.

Finally, the national physics community has grappled more than scholars in almost any other area with the difficulties besetting their discipline. The presence on the Virginia Task Force on Physics (VTFP), formed in fall 1995, of two officers of the American Physical Society brought the benefits of that national conversation to Virginia. The conversation was further broadened by a high-level industrial representative on the task force, in the person of a retired vice president for IBM, Science and Technology. Other members were physicists from the Jefferson Lab, Council staff, and physics faculty and students from Virginia's colleges and universities.

The task force saw it as the mission of Virginia's physics programs to

- Produce excellent and diverse students at the bachelor's, master's, and doctoral levels who are trained in a broad range of skills for today's competitive job market.
- Create a research climate conducive to supporting both basic research and high-technology industry in the Commonwealth.
- Provide part of the broad scientific and technical foundation required by other scientific, engineering, medical, and business disciplines and contribute to the general education of all college students in Virginia.

The VTFP designed a review that aimed not at identifying programs that might be eliminated but at determining the current strengths and weaknesses of the existing set of programs in the state in order to make recommendations on how they could be improved to meet these goals.

The review has occurred in several stages. After consulting with the college presidents, the chief academic officers, the relevant deans, and the physics department heads, the task force asked that each program in the state submit a self-study by mid-December. In January, February, and March, smaller teams of task force members visited six of the state's thirteen senior institutions with physics programs to get a closer look at a wide variety of programs serving different kinds of students in very different settings. The information thus collected has led to the recommendations in this report.

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Part II: The National Context

The study of physics programs in Virginia has taken place in the context of a much larger national discussion. As is true for most of the scientific disciplines in the U.S., this is a time of considerable turmoil and uncertainty for physics. This is true whether the focus is on the teaching of physics at college and university levels or on research.

This uncertainty is not due to any conviction, held widely by scientists at the end of the 19th century, that we are near the end of what can usefully be discovered about the physical world. On the contrary, many sub-fields of physics are as vigorous and exciting intellectually as they have ever been. It is not that nature is running out of mysteries; rather, it is that what has been America's increasing interest in and support for solving them seems to be flagging.

Moreover, physics continues to be recognized as a core discipline, not only in the study of nature but also in the preparation of many other types of scientists, doctors, and engineers. This is reflected in the fact that physics departments nationally continue to "provide service courses for other majors and enrolled approximately 360,000 students in introductory physics courses in 1994-95."[3]

The turmoil in physics education is due rather to political and economic factors that have affected all the physical sciences and engineering. The explosive support for physics in particular following World War II, and especially after the launch of Sputnik, was fueled in large part by the imperatives of the Cold War. This support entailed the infusion of massive amounts of federal funding for research and the concomitant exponential growth of both the national labs and university physics programs. The physical sciences were widely, and correctly, seen to be fundamental to the creation of a strong national defense. With the end of the Cold War , other issues have come to the fore, and a consequence has been diminished national commitment to leadership in this and other branches of the physical sciences and engineering. According to the National Science Foundation, spending on the medical sciences went up 88 percent between 1987 and 1994 while support for physics increased by about 40 percent, "less than for any other major discipline" in science. "'The century of physics is over,' says Robert L. Park, director of public information for the American Physical Society. "We're entering the century of biology.'"[4]

Thus it is widely believed that given bipartisan pressures to balance the federal budget, federal support of research and graduate education in the physical sciences -- including physics, and engineering -- will not increase for at least six or seven years but may in fact decline over the next decade by anywhere from 10 to 30 percent in real terms. Meanwhile large-laboratory industrial support for research in physics, and hence the demand for physics researchers, has also decreased somewhat in recent years. The reasons for this are complex and related to global competition, and the likely duration of the cutbacks in industrial research in the

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physical sciences is not certain. Finally, universities are facing not only increased competition for federal dollars but stagnant or declining state support, leading them to look much more critically at expensive programs, especially those without large numbers of students in them.

And student interest in physics, as measured by undergraduate major and entering graduate student numbers, has flagged. This is partly due to the responsible way the physics community has acted in the present circumstances. In the last few years, the community, through the American Institute of Physics(AIP) and the American Physical Society (APS), has been providing up-to-date and realistic data on the current and near-term future for traditional employment of physicists, especially at the doctoral level. This has had the expected effect of modest but measurable decline in the number of physics majors at the bachelor's level and entering graduate-student level: national trends in enrollment, summarized annually by the AIP, have been downward. For example, over the four-year period ending in 1995, the enrollment of juniors in physics programs dropped to the level that obtained in 1980, which was itself a thirty-year low. Similarly, during the last three years, entering graduate enrollments in physics nationally have dropped by 22 percent in Ph.D.-granting departments and by 17 percent in masters-granting departments,[5] although due to the time lag for Ph.D. graduation, the number of doctorates awarded will not begin to decline noticeably until the 1998-99 academic year.

These decreases reflect awareness on the part of prospective physics undergraduate and graduate students of the current decline in employment possibilities in traditional jobs directly involving physics. Less well recognized by students and faculty alike, however, and becoming more important over time, is the movement of engineers and scientists, including physicists, into less traditional careers: state and local government, finance, banking, medicine, law, multimedia, big business, and young entrepreneurial businesses. In the past, many of these opportunities were filled by humanities and social science majors who later specialized in their graduate education in business, medicine or law. More recently, students prepared themselves for many of these careers by specializing in business as undergraduates. Today, many baccalaureate science and engineer majors, both undergraduate and graduate, are moving into these non-traditional careers, often with great success.

With the rapid development and ubiquity of technology and the development of the information society, graduates who have a good foundation in mathematics, the physical sciences, and computers -- especially those who have writing and communications skills -- are at a great advantage in the employment market. For example, a recent newspaper article on the improved job prospects of this year's college graduates quotes a Signet Bank representative, who says that "this year, the company hired 'analyst-type whiz kids' who've excelled in areas such as math, statistics, or physics.'"[6] A firm foundation in the mathematical and physical workings of modern technological society constitutes not only an essential part of a liberal education in the modern world but the grounding for any career related to technology, computers, or information and data management.

State and local governments have begun to recognize the importance of strong science, engineering, technology, and computer programs to economic development, especially in attracting industries that offer higher-paying jobs with growth potential. Motorola's decision to locate its microchip facilities near Richmond, based partly on the proximity of such programs to train its workers, is replicated every day in places such as California's Silicon Valley; North Carolina's Research Triangle Park; Austin, Texas; and the Route 128 corridor around Boston, Massachusetts.

For these partnerships to work, however, ties must be developed and nurtured which benefit both parties. There are too many instances in which colleges and universities (and sometimes individual departments within them) remain separated from their local and regional communities. Virginia's state economic-development and higher-education agencies have developed near-term and long-term strategies to promote the connection between the state's colleges and universities and its new industries, such as the $7 million Motorola and IBM fund that should ensure the capacity to hire and retain first-rate engineering faculty.

Recommendation:

> that state economic-development and higher-education agencies should support Virginia's colleges' and universities' attempts to enhance their educational programs in physics in ways that open up and demonstrate new opportunities to graduates in fields not normally thought to require a background in physics but for which it is excellent preparation. Such efforts should be recognized as promoting economic development for local communities and the state.

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Part III: Physics Programs in Virginia

The physics programs in the Commonwealth's universities and colleges reflect the diversity of sizes, locations, and missions of the institutions (see Table 1). The programs range widely in student and faculty numbers, numbers of options, and clientele. At the same time they have, not surprisingly, many similarities. Perhaps more than any other core academic discipline, physics has an extremely well-established canon. When faculty members from different institutions discuss their programs, they rarely focus on what subjects or concepts are taught;. rather they are apt to discuss what textbooks they use for, say, the electricity and magnetism course or for the mechanics course.

This coherence is a strength in many ways: because of the central position that physics occupies in both a thorough liberal-arts education and a solid scientific and technical education, the integrity of the discipline is important. However, the concordance may reflect a weakness as well -- an unwillingness or an historical lack of necessity for the discipline to extend itself or broaden its scope. In this regard, the diversity of programs in the Commonwealth is encouraging: they constitute a rich gene pool from which the most successful curricula for various types of students can develop.

All but two of the Commonwealth's fifteen senior institutions offer bachelor's degrees with majors in physics. In addition, nine of the institutions offer master's and four offer doctoral degrees. With similar core curricula, they differ in the following ways:

- Virginia Tech and the University of Virginia offer a full range of undergraduate and graduate courses and degrees in the settings of major research universities. William and Mary offers similar programs, but in an environment that is largely that of a liberal-arts college.

- Old Dominion University is conscious of its position as the Commonwealth's only physics Ph.D.-granting institution in an urban setting and explicitly recognizes and works to accommodate the variety of students that are attracted to its programs. ODU's proximity to the Jefferson Laboratory and NASA Langley gives it access to major research facilities, and the university's commitment to building the program's strength has led to the recent expansion and diversification of its faculty, the development of new facilities, a 60 percent increase in its number of graduate students over the past six years, and the potential to become a nationally recognized department.

- Christopher Newport has a similar commitment, in its undergraduate and master's programs, to the working adult. Its applied physics program is offered by a department where physics is joined with computer engineering, computer science, and information science. It draws on those academic areas in preparing students to work in the microelectronics industry.

TABLE 1
PHYSICS PROGRAM GRADUATES AND JUNIOR, SENIOR, AND GRADUATE MAJORS, 1990-1994

Institution	Program	Degree	5-Yr Average--Grads (not incl. double majors)	5-Yr Average--Majors
Christopher Newport University	Applied Physics	BA/BS	4.2	30.1
College of William and Mary	Physics	BS	20.0	43.9
	Physics	MA/MS	10.2	16.2
	Physics	PhD	6.6	41.2
George Mason University	Physics	BA/BS	8.0	23.4
	Applied and Engineering Physics	MS	6.0	10.3
James Madison University	Physics	BA/BS	6.6	19.8
Longwood College	Physics	BA/BS	12.4	27.4
Mary Washington College	Physics	BS	9.0	21.5
Norfolk State University	Physics	BS	2.8	14.4 (approx.)
Old Dominion University	Physics	BS	6.4	20.6
	Physics	MS	4.6	2.3
	Physics	PhD	3.0	37.1
University of Virginia	Physics	BA/BS	14.0	31.2
	Physics	MA/MAT/MS	5.8	40.5
	Physics	PhD	10.4	55.0
Virginia Commonwealth University	Physics	BS	7.4	27.9
	Physics and Applied Physics	MS	2.8	7.8
Virginia Military Institute	Physics	BS	2.4	6.7
Virginia Polytechnic Institute and State University	Physics	BA/BS	17.4	69.8
	Physics	MS	8.8	19.2
	Physics	PhD	5.2	28.4
Virginia State University	Physics	BS	3.6	19.2
	Physics	MS	2.4	12.1

- George Mason's undergraduate and master's programs take advantage of the physics department's close ties with George Mason's Institute for Computational Sciences and Informatics to prepare their mostly working adult students for employment in the high-technology companies and laboratories in Northern Virginia. In contrast to CNU, the program attempts to train generalists, although ones with strength in computation.

- With a relatively small number of faculty, VCU has chosen to concentrate on a single area of expertise, condensed matter physics, in order to be able to offer several courses related to the fundamentals and applications of this technologically important field. With the arrival of Motorola in the area, opportunities will exist for this department, in cooperation with VCU's new School of Engineering, to establish significant industrial ties.

- Virginia State and Norfolk State have traditionally served the African-American population of Virginia and the nation. While they are becoming more diverse, both institutions work toward increasing the number of African-American physicists at both the baccalaureate and master's levels. Since the national record for producing minority scientists is dismal -- approximately one-half of one percent of the Ph.D.s in physics are earned by African-Americans -- both institutions are committed to nuturing black students to go on to doctoral programs.

- Four institutions offer only the baccalaureate degree in physics. Happily, after considerable disruption, James Madison's physics program has conditional approval for a physics major with three different tracks: fundamental studies, which will prepare students for graduate work; applied physics, focused on preparing them for jobs in business and industry; and a 3 +2 physics/engineering program.

- The last is similar to the very successful program at Longwood College, which provides entry to undergraduate or graduate programs in engineering for students who prefer a smaller college environment and for students who may not be prepared to go directly from high school into a selective and competitive engineering program. Longwood attracts and graduates a remarkably large number of students. Mary Washington College, like Longwood, has a very small number of faculty who nurture students in a small liberal-arts college setting.

- Finally, VMI's physics program operates in a unique institution. The program provides not only a physics degree to its most academically well-qualified students but also the foundational support to its other programs in the sciences and engineering, disciplines strongly stressed in its mission statement.

As it visited institutions and read reports, the task force identified a number of

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practices that it considered exemplary in the programs, as well as some weaknesses. What follows is a list of recommendations to the physics programs in Virginia and examples of how some institutions have shown how these recommendations might be addressed.

The physics major

1. Inter-institutional cooperation

Undergraduate physics majors within the Commonwealth are being given a wide range of concepts with which to understand the physical world. It seems to the task force that these core concepts are being taught with academic rigor at every institution, although some programs have greater strength in their lower-division and some in their upper-division courses. As a result, some programs are able to develop students who might well transfer into other majors at less nurturing institutions. However, the task force also concludes that when they reach the upper-division courses, those students may not have access to a wide enough range of advanced courses. At the graduate level, almost all institutions could benefit from a broadening of their course offerings. Therefore, the task force makes the following

Recommendation:

that programs in the Commonwealth cooperate in offering courses to students at all levels of the curriculum.

Subsidiary recommendations:

- Small undergraduate programs should make use of the teaching resources of nearby research institutions to enrich the learning opportunities of their students. They might do this by inviting postdoctoral and advanced graduate students from those institutions to teach courses, in exchange for which they would receive adjunct pay, the mentoring of some of the best physics teachers in the Commonwealth, and experience in the kind of teaching job to which many of them aspire.

- Departments can also form alliances across institutions to permit students who start their course of study at one college to complete it at another. Many physics students we talked to expressed career interests -- for instance in engineering or computer science -- that could be supported by articulation agreements.

For example

- Longwood College's 3+2 program, -- in which physics students transfer in their fourth year to Old Dominion University, where they complete an engineering degree -- is a model that might be widely imitated.

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- Institutions can form partnerships to share the teaching of upper-level and specialized courses, bring in guest speakers, and support and do cross-assessments of senior research projects.

For example

- Longwood and VMI have formed partnerships with Hampden-Sydney and Washington and Lee, respectively, to co-sponsor visiting lecturers. In the past, Longwood relied on a Hampden-Sydney faculty member to teach one of its advanced courses at Longwood, and students can take classes in either department.
- Virginia State University has a similar arrangement with Virginia Commonwealth University, which should be more widely advertised to students.
- George Mason has been involved in the Consortium for Upper-Level Physics Software (CUPS), in which about 30 physicists from around the world have joined to develop software packages that are now coming on the market to outstanding reviews.

- Research departments that are currently forced to offer important advanced topics only every two or three years could share the responsibility of such courses by allowing students to take courses by commuting to neighboring institutions, two-way video-conferencing or other telecommunicated instruction between more distant institutions, or semester-length mini-sabbaticals for the teaching faculty. The Virginia Physics Consortium could be the coordinating body for such efforts.

For example

- In another discipline, the Virginia Consortium for Engineering and Science (VCES), formed in 1993 and headquartered in Hampton, has successfully organized a network among Virginia's graduate science and engineering schools. This consortium offers video-linked courses and cross-registration of course credits among the participating institutions.

2. Career preparation

As we have mentioned several times in this report, one of the most pressing issues that physics programs face is the need to inform students about and prepare them for a much broader range of careers than has been true in the past. Indeed, fewer than half the students polled by the task force visiting teams intended to pursue a career directly related to academic or research physics. While the undergraduates generally felt hopeful about their career possibilities, the graduate students were less sanguine about the degree to which their programs prepared them for, informed them about, and encouraged them to pursue non-traditional careers.

As the descriptions above make clear, some departments have addressed that challenge head-on, for instance by designing professional master's programs geared to a specific job market. Others do an excellent job of providing their undergraduate students with a liberal-

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arts education grounded in analytic and problem-solving skills that should serve the students well in a wide range of careers. But the process of ensuring that curricula meet the needs of program graduates is a continuous one. Therefore, the task force makes the following

Recommendation:

> that all physics programs at all levels rigorously examine their curricula to assess the balance in the education they offer in view of the wide spectrum of employment opportunities their graduates will have in the future.

Subsidiary recommendations:

- Programs should have clear curricular goals, developed in consultation with employers, alumni, and students. They should then assess student learning and survey students, alumni, and employers to assure themselves and their constituents that they actually develop those skills and impart that knowledge, and that they have prepared their students for their lives as citizens and workers. These goals and results will help them continuously improve their curricula and decide in what areas any new hires should be made.

For example

- ▸ Longwood College provided the task force with very good information about what its graduates are doing and their grade-point averages at Old Dominion University and other institutions to which they had transferred.
- ▸ The interdisciplinary and pragmatic curriculum of James Madison University's College of Integrated Science and Technology is an innovative attempt to prepare students to work in the business of science and technology. The magnitude of the investment and scope of this effort, as well as its potential to serve as a model, makes evaluation of this program essential. Careful assessment of student learning and the tracking of graduates should also enable the college to continually adjust its curriculum to effect an optimal balance between the rigors of a traditional science curriculum and the practicalities of a more workforce-oriented one.

- Programs should require that all students have practical experience in problem-solving, physics-style. This may be a senior research project, a practicum, or an internship. Such projects can serve as culminating and integrating experiences for students, and they often lead to more informed career choices. Faculty should be recognized and given formal teaching credit for establishing placements for and supervising the research of students.

For example:

- ▸ One student wrote the task force to suggest that faculty formally list their research activities to enable students to match their interests with the appropriate mentor. The department's homepage would be a logical place to post such a list.

- The senior research project at the College of William and Mary is recognized by both faculty and students as a central element of the undergraduate major. The students appear to put considerable thought into the choice of the research project, and there are a large range of possibilities available in the physics and applied science departments and at the Jefferson Lab, NASA Langley, and industrial sites.
- At Old Dominion University, all undergraduates are guaranteed the opportunity to complete a practicum, in addition to the requirement for a senior thesis in the physics program. While the senior thesis and practicum can be combined and may involve work at the Jefferson Lab or NASA Langley, the practicum may be fulfilled in other ways as well. The use in non-traditional settings of skills developed as a physics major can demonstrate to students the transferability of those skills.
- Students at Norfolk State University have a rich array, and unusual awareness, of research opportunities. Undergraduates participate in internships and summer research projects to an impressive extent, and the required senior project (and its assessment) is one of the program's excellent features.

- Programs should ensure that their students can and do develop key skills that lie outside the traditional physics currciulum, such as oral communications and computer skills. Physics faculty should stress and give students the opportunity to practice those skills within the physics program, develop interdisciplinary offerings, and remove barriers -- such as rigid tracks for progression or faculty disapproval -- that prevent motivated students from taking courses, dual majors, or strong minors in other fields. In turn, physics departments might consider developing a physics minor for students majoring in business or public policy. Institutions should remove barriers that prevent students from taking appropriate courses in other programs, such as extra tuition charges or other forms of discouragement.

For example:

- The program at Christopher Newport University, rather than focusing primarily on traditional graduate-school-bound undergraduates, is adapted to its environment and clientele. In an innovative department where physics is joined by computer sciences, the applied physics program is oriented toward microelectronics and fits with the computer-related programs offered by the department.
- The University of Virginia's recently revised Bachelor of Arts in Physics is an innovative adaptation of the physics curriculum for those students not planning to go on to graduate school. It permits those students to take more applied courses that illustrate and integrate basic scientific principles for the advanced theoretical physics courses taken by the Bachelor of Science students in the fourth year.

- Advising is a key component of the preparation of students for the world of work. While they seemed quite satisfied with the guidance they received from faculty in the study of physics, students uniformly complained about career advising. Faculty need to give systematic attention to informing themselves and then advising students about the wide variety of careers open to them, including work in business and industry and teaching in primary and secondary schools and in community. Many faculty find it difficult to counsel students about non-academic job opportunities -- contacts in business and industry need to be developed for this, if for no other reason. Faculty need also to meet with groups of students regularly to discuss possible careers, possibly supplemented by career seminars and panels of alumni who describe their working lives and how students might prepare for the realities of the working world.

For example:

- George Mason University physics and astronomy students are provided with a handbook that not only explains the requirements for the degrees but provides candid and useful information about physics, physics employment prospects, the university, the physics department, the Society of Physics Students (SPS) club, why one might consider graduate school, and several other related topics. The page on "How Can I Improve My Chances of Getting a Good Job?" should alert students at an early stage to begin thinking about and preparing for their employment ambitions.
- Many programs are trying to provide more help to students, both in the form of explicit inclusion of skills that are valued in the workplace and in the form of more and better placement assistance. Alumni are beginning to be recognized as a major resource for career planning and as a network for job placement.

The role of physics in general education and service to other majors and to the community

1. General education

Most physics departments consider their primary role to lie in offering a major program of study in physics and introductory courses for other science majors. But their role in providing general education core courses has taken on added significance in the nineties. The liberal education of all students requires scientific literacy. According to the American Association for the Advancement of Science, "Science is one of the liberal arts and should be taught as such." Only with a basic understanding of science will people be "empowered to participate more fully and fruitfully in their chosen professions and in civic affairs."[7]

For many years introductory physics courses tended to be specialized and usually geared toward the science major. But over the last decade, increased emphasis on the need for more science education has resulted in many new general-education course offerings in an attempt to make physics more attractive for students who enter college with increasingly diverse preparation, interest, and abilities in mathematics and the sciences. Many physics programs have developed courses on topics that address questions students actually have about the natural world -- such as those associated with energy, light, sound, and music -- to fill this need.

To some scholars, this development has not been welcome. A recent report by the National Association of Scholars (NAS), for instance, includes in its chapter entitled "The Decline of Rigor" a description of the changes in the science requirements of colleges and universities nationwide in the years from 1914 to 1993. The NAS is particularly concerned about the tendency of such courses to "contain less mathematics [and to be] less likely to have laboratory requirements."[8] However, as the NAS report itself acknowledges, "Non-science majors may learn more if they are not overburdened by having to master techniques and skills for which they have little aptitude and will have little use." Moreover, traditional courses geared to the majors, in order to cover all the content knowledge that potential majors need to progress in the physics curriculum, have sometimes resulted in the memorization of facts and solutions to problems rather than providing students opportunities to learn and practice the means by which they were solved or to provide a coherent and comprehensible overview of the scientific enterprise.

Given these observations, the task force makes the following

Recommendation:

that physics programs pay more attention to and reward faculty for the development of new general-education courses.

For example:

- Virginia Commonwealth University has asked one physics professor to focus his energies on revamping the department's general-education courses. Changes include use of the new teaching technologies.
- A course that has been especially successful in conveying concepts of physics to students in the arts, humanities, and social sciences is "How Things Work" at the University of Virginia. Created in 1991 by Prof. Louis Bloomfield, this course offers a non-conventional view of physics and science that starts with whole objects and looks inside to see what makes them work. The course aims to convey an understanding of the concepts and principles of physics and science by finding them within specific objects of everyday experience. Interestingly, the university has supplemented the typical terse catalogue description with full-color posters placed around campus to acquaint students with this course and others for non-science majors. Prof. Bloomfield has written a textbook entitled *How Things Work* that will be published by John Wiley & Sons in 1996. Word about the course has spread, and at least three other state institutions are offering or planning to offer a similar course. It is not yet clear, however, whether the success of this new course can be attributed to its non-conventional approach or to an extraordinary teacher.
- Another exciting new development is the publication of *The Sciences: An*

Integrated Approach by Profs. James Trefil and Robert Hazen, an outgrowth of their "Great Ideas In Science" course at George Mason University. In it they integrate physics, astronomy, chemistry, earth science, and biology in an attempt to make students broadly literate in science. Such a course would seem eminently appropriate to replace the usual science requirement for non-science students.

2. Service to other majors

Physics programs face another challenge: providing service courses for programs for which physics is a prerequisite. They can do this either by teaching service courses specially designed for students in other disciplines or by including material appropriate for such students in their standard introductory courses. In planning such courses, physics departments should study their own experience with mathematics service courses. The task force found a nearly ubiquitous frustration among the physicists it met in the course of the study regarding the failure of their colleagues in mathematics to consult them about the kinds of quantitative skills and knowledge physics majors need. (Evidently this feeling is not confined to Virginia: the University of Rochester decided not to eliminate its doctoral program in mathematics in part in exchange for the department's promise to better tailor its calculus courses to the needs of scientists and engineers.) This frustration should alert physics faculty to the need to communicate with faculty in programs for which they are providing the foundational knowledge.

Physics prerequisites for other programs are in some cases critical to those programs' success: any institution without a strong physics program will be unable to attract the best pre-med majors, and a weak physics department can hamstring an engineering school. But those service requirements can entail a serious strain on departmental resources when those programs are initiated or grow in size. The numbers at large universities with major engineering schools are almost overwhelming; for example, Virginia Tech has more than 3200 non-physics majors enrolled annually in its service courses. Enrollments such as these preclude some innovative approaches that are labor, space, and equipment intensive, such as the "discovery method" developed by Priscilla Laws and others at Dickinson College, although they still permit the initiation of others such as the studio physics approach pioneered by Jack Wilson at RPI. But such enrollments do create the need for focused attention to the methods of instruction for large lecture courses. Some departments, rather than resorting to the traditional solution of "chalking and talking," have made use of new teaching technologies to increase the amount of active learning in an environment typically characterized by the enforced passivity of students.

The task force therefore makes the following

Recommendations:

that physics departments work closely with their colleagues in other departments to ensure that their curricula fit together well, and that they explore new teaching techniques and technologies to enable more active learning in their large lecture courses.

For example:

- The two largest audiences for service courses are usually pre-medical students and engineering students. At the University of Virginia and Virginia Tech, issues related to the content and presentation of the courses are handled for the courses for engineers by joint committees of the engineering school and the physics department. Thanks to the efforts of the faculty teaching the courses and to the communication fostered by the committees, student and faculty satisfaction with the courses has improved.
- Applications of technology to the development of new modes of instructional delivery among state institutions is fragmented, at best. An exception is Christopher Newport's use of ClassTalk, an interactive computer system designed to make students more active learners in large introductory classes. ClassTalk was developed through a cooperative effort of CNU professors and a local entrepreneur. It is currently in use at several prestigious institutions, such as Harvard and Carnegie Mellon, but appears virtually unknown at other Virginia institutions.

3. Service to the community

The teaching responsibilities of physics departments reach beyond the campus: physicists share the responsibility for science education at all levels in the Commonwealth. This can involve direct interaction with primary- and secondary-school students or community-college students, or it can focus on the preparation of and in-service education for teachers in those programs. The task force was pleased to learn that most institutions have outreach programs with an impressive range of offerings to K-12 schools, if not to community colleges, from special courses to strengthen and update teachers' knowledge of physics and astronomy to visits and lectures at nearby schools.

Recommendation:

that the physics programs in Virginia consider it part of their mission to ensure the excellence of the entire science education of Virginia's students, from primary school through the two- and four-year institutions of higher education.

For example:

- At Virginia Tech, the physics department has an impressive array of outreach activities which have been recently extended into Floyd County. With grant support, undergraduates serve as mentors to high-school physics students through the use of electronic mail and bi-weekly visits.
- Similarly, the physics department at the University of Virginia has a history of providing courses (both face to face and telecommunicated) and other support for large numbers of K-12 teachers. The department provided the major initiative for the University of Virginia Center for Science Education and presently houses the center.

▸ Finally, for over 20 years VMI has worked with precollegiate institutions at all levels, but particularly high schools, in stimulating interest in and enthusiasm for science through the design and use of lecture demonstrations. Teachers from Virginia and almost every other state and many foreign countries have participated in the summer workshops. A special workshop for science teachers in Native American schools was held in 1993, supported by the Bureau of Indian Affairs.

Part IV: Students

1. Undergraduate experience

To judge by those with whom the task force visiting teams talked, undergraduate students in the physics programs in Virginia are a very satisfied group. They have every reason to be: their programs generally have many of the hallmarks of a high-quality undergraduate experience, as summarized from the literature by the Education Commission of the States.[9]

- Physics programs are characterized, for instance, by **high expectations**. Students in the programs reported that they felt themselves to be an elite group, and their entering grade-point averages, usually at or near the top for their institution, bear out that assumption. They are also elite in that course-taking patterns revealed by national transcript studies suggest that science majors are generally more confident in their verbal skills than humanities students are in their quantitative skills.[10] Physics students in Virginia whom the task force interviewed generally reported that their programs challenged them significantly, as suggested by the fact that nearly all said that they had of necessity formed study groups in order to meet the demands of their programs.

- Thus the programs exhibit another characteristic of programs that work: **collaboration.** Such cooperative effort not only aids learning by making students into teachers, it also teaches teamwork skills that are increasingly necessary in the work world. Student interaction is a predictor of satisfaction as well. Interaction among students can be encouraged in a number of ways: group research projects, the formation of study groups, and an active Society of Physics Students (SPS) are some that come to mind. The task force talked with students who proudly reported that their SPS clubs had brought in speakers on relevant topics, such as the local employment situation, or planned field trips to appropriate facilities. Another way of facilitating interaction among students is to establish electronic-mail accounts for them. This can help create a sense of community at institutions with a high percentage of commuter students. Finally, during the site visits, several undergraduate students expressed concern about the lack of available or dedicated space in the departments for study sessions, physics-club activities and informal gatherings. Consequently, those institutions that do not have facilities for undergraduate physics majors to meet and study in informal settings should consider allocating space for such activities, again particularly if they have a large proportion of commuting students.

- Some of the programs the task force visited showed **respect for diverse talents and learning styles**. The Mary Washington program, for instance, was praised by students for the variety in teaching styles of its three faculty members. Longwood College is notable for the degree to which it takes students who are less sure of themselves or less well prepared and makes them into credible scientists. These small programs are also remarkable for their close attention to students during the **early years of study**, found to be critical in students' ultimate success.

- Physics programs are generally characterized by a sequential curriculum that produces a high level of **coherence in learning**. In contrast to the typical physics curriculum, the National Association of Scholars, in agreement with the literature on what makes college work for students, cites the decrease in the number of courses with prerequisites in the general-education curriculum as a sign of its decline in rigor.

- Those programs that provide students with opportunities for research and practica throughout the curriculum are meeting a number of criteria for excellence: they are providing **active learning**, the **ongoing practice of learned skills**, and **synthesizing experiences** for their students. In addition, students in them are provided with the opportunity **to integrate education and experience.** Finally, students with practical experience are much more employable when they finish their programs.

- On some campuses students remarked on their ability to contact faculty in their labs for immediate feedback on their work. They not only gained the benefits from fine in-class instruction -- they received the tutorial help associated with the best kind of college teaching and learning. According to both common sense and the research on student success, **assessment and prompt feedback** and **out-of-class contact with faculty** are two more hallmarks of a good undergraduate education.

2. Graduate experience

The graduate students generally struck the visiting teams as a less satisfied and less active group than the undergraduates. By the time students enter graduate school, they seem to be focused less on general academic preparation and more on preparing themselves for a particular kind of job, and many expressed uncertainty about whether their programs had adequately prepared them for or informed them about the world of work. The task force has concluded that self-contained master's programs, in particular, should be designed to prepare students for non-academic employment -- they should all, in short, be professional rather than "terminal" programs, an unfortunate but sometimes all-too-descriptive label. And programs have a responsibility to inform all incoming graduate students about their prospects for employment, based on the program's record in placing its graduates.

3. Alumni as a resource and network

Alumni are a good source of information about what a program's graduates go on to do, how well the program prepared them for their working lives, and how it might do the job better for its current students. Some of the programs were in contact with their alumni on more than a random and anecdotal basis, while many were not. Besides advising the faculty on how to keep the curriculum in line with the skills needed in the workforce, alumni can mentor students in the programs by serving on panels to explore their varied career choices and how to prepare for them, as well as by providing internships and an employment network. When programs solicit that information, help, and advice, they need to make clear to the alumni and to the students who will become alumni how they are using the information provided to improve the program.

Recommendation:

that all programs track their undergraduate major and graduate alumni and make use of alumni contacts as mentors for their students and as advisors to the faculty. The task force suggests that programs set up homepages and alumni listserves, perhaps maintained by students in the program, as one easy way to keep in touch with their graduates.

Part V: Faculty

1. Distribution of responsibilities

The task force found on its campus visits that the physics faculty at Virginia's colleges and universities are typically very dedicated and hard working. On the whole they seem to be first-rate teachers but stressed by the competing demands of the classroom, their research program or laboratories, their mentoring of individual students and study groups, and the shared administrative duties of their institution. The ratio of faculty to physics majors was comparatively high, which allows these students significant opportunities for individual attention. At the smaller institutions, the entire physics faculty (usually a small number) was given excellent marks by their number-one customers, the students. In the larger institutions, the task force had predictably more mixed impressions, possibly because of the large service enrollments and possibly to some degree due to the centrality of research in the lives of faculty who teach at the research institutions.

Table 2 (next page) displays the rounded number of full-time-equivalent state-supported physics faculty (FTEF) at each institution, the number of total student credit hours (SCH) taught by each physics department, the 1994-95 credit hours per FTEF taught in each program, and the total amount of sponsored research the program reported generating annually. Sponsored research funds cannot reliably be calculated or compared per FTEF, since the time periods vary and the staff numbers may have been different when the research was funded. The degree to which a department has the "critical mass" of faculty necessary to do high-quality research is affected not only by its numbers of teaching faculty but by its non-state-supported faculty and research staff and its cross-disciplinary interactions. Finally, faculty effort spent in outreach activities is hard to quantify but is one important component of program effectiveness.

The physics departments under scrutiny in this study did not express worry about any imbalance between the role of the faculty member as teachers and researchers. Although that balance varies according to institutional type, most physicists see research at some level as a necessary part of their maintenance and growth as teachers and their capacity to provide hands-on experience to their students. The visiting teams did note, however, a very natural concern that there be a fair distribution of the tasks that make up modern academic life: teaching, research, administration, and outreach.

TABLE 2
FACULTY AND WHAT THEY DO

Instituti on	FTEF	1994-5 SCH (lower-div)	1994-5 SCH (upper-div)	1994-5 SCH (grad)	Total SCH/FT EF	Sponsored research $ annual average
CNU	6	2,180	666	315	527	$1,138,221 (1994-95)
GMU	14	1,474	3,483	366	380	$340,978 (1994-95)
JMU	10	3,592	202	21	382	$48,743 (5-yr average)
LC	2	884	397	0	641	$0
MWC	3	1,326	338	0	555	$0
NSU	8	4,355	332	33	590	$286,500 (1993-96)
ODU	19	6,147	862	940	418	$1,112,387 (1994-95)
UVA	35	11,762	744	3,242	450	$5,474,000 (5-yr average)
VCU	9	5,983	554	176	746	$397,512 (5-yr average)
VMI	5	29	1,330	0	272	$0
VPI	31	13,247	1,647	1,033	514	$2,340,000 (1994-95)
VSU	4	1,590	50	92	433	$279,574 (3-yr average)
W&M	28	3,456	648	1,254	191	$2,046,469 (1991-92)

Recommendation:

that all programs review the balance of responsibilities carried by each faculty member to ensure a fair and equitable, but not necessarily identical, distribution of tasks.

For example

- On the basis of Virginia Commonwealth University's strategic planning efforts (which included all the faculty), each faculty member has negotiated a contract that details his or her intended contributions to the program in the four areas of responsibility listed above. The balance among the areas varies according to the strengths and interests of each faculty member and the needs of the department and institution and will be renegotiated periodically.

2. Faculty turnover

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Table 3 shows the demographic characteristics of the physics faculty in Virginia: the total headcount, their average age, and the rounded percentage of them who are white, black, other minority, male, and female.

As its age distribution suggests, a large number of Virginia's physics faculty -- like those elsewhere in the nation -- were hired in the academic boomtime of the first few decades after World War II, and in some longer- established programs a significant number are approaching retirement age. This age distribution has two major effects on students. First, in general older faculty members' predominately academic experience often has not prepared them well to educate students for or advise them about the current broader range of career options. Secondly, the lack of non-academic employment experiences makes them less able to act as a nexus between potential industrial employers and graduating students.

TABLE 3
FACULTY DEMOGRAPHICS IN PHYSICS

Institution	Mean age	% white	% black	% other minority	% male	% female
CNU	43	89	0	11	89	11
GMU	51	81	5	14	62	38
JMU	53	100	0	0	100	0
LC	51	100	0	0	100	0
MWC	58	67	33	0	100	0
NSU	50	29	43	29	86	14
ODU	46	88	6	6	88	13
UVA	53	85	0	15	96	4
VCU	48	63	0	38	88	13
VPI	53	73	0	27	90	10
VSU	55	25	50	25	100	0
W&M	55	100	0	0	95	5
All	52	82	5	14	90	10

Faculty who are eligible for retirement or who qualify for one of the state's buy-out programs sometimes do not take advantage of these opportunities because they cannot, after retirement, continue to do what they enjoy most: do physics and share this joy with students. In some physics programs in the state, becoming an emeritus professor also results in the loss of an office, telephone, access to computing facilities and other supports that one has enjoyed as a faculty member. Institutions who have significant numbers of physics faculty approaching retirement age should evaluate their treatment of emeritus faculty and make necessary changes to eliminate the fears of potential retirees. If those fears were addressed at relatively modest cost, faculty members might be more willing to retire, thus allowing for the recruitment of the next generation of physicists.

When a program is able to hire new faculty members, it is sometimes stymied by the unavailability of start-up funding, the money necessary to set up a laboratory and research program. Faculty and administrators at several of the institutions visited by the task force noted the lack of resources that could be devoted to both attracting and kick-starting the career of a promising young scientist. The problem is also evident when an institution attempts to recruit a well-known mid-career scientist at another academic or industrial research institution. Such hires should be balanced against departments' needs for a more even age distribution; at the same time, they can add great scientific stature to a department and more than compensate for the buy-in cost with the subsequent sponsored research funds that follow these pedigreed scientists. As the world-class US industrial research labs (IBM, AT&T, Xerox, Exxon, etc.) have downsized over the last five years, and as the turmoil continues in the former Soviet Union, a large number of first-rate mature physicists have become available for academic positions. However, the competition for them has been fierce, and only the larger, more endowed institutions nationally have been able to afford the startup costs. To the degree that Virginia can attract more of these world-class scientists, it will simultaneously raise the scientific stature of the Commonwealth's physics departments, give students a look at industrial career options, and have a net positive influence on the research budget.

Recommendation:

> that the institutions ensure the continued vitality of their physics programs through creative early-retirement programs and emeritus options, as well as through adequate start-up funding for new faculty who are both at the beginning and in the middle of their careers. For their part, programs should, without compromising in the least their academic standards, work to increase the representation of physicists experienced in work outside the academy and women and minority physicists, as well as to develop a better age distribution among their faculty.

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Part VI: Recruitment and Retention of Women and Minorities

1. Undergraduates

The statistics for Virginia's science departments show that the student statistics do not reflect the demographics of the Commonwealth or even of higher education with respect to women and minorities, as Table 4 demonstrates. Of Virginia's 424 upper-division undergraduates majoring in physics in 1994-95, 86 percent were white, eight percent black, and five percent other minority; 82 percent were male, 18 percent female. There were 252 graduate students studying physics in the Commonwealth in 1994-95, of which 84 percent were white, 5 percent black, and 11 percent other minority; 86 percent were male, with 14 percent females.

TABLE 4
STUDENT DEMOGRAPHICS -- PHYSICS MAJORS

Institution	Average age	#/% white	#/% black	#/% other minority	#/% male	#/% female
CNU	u.g.*: 30 grad: 29	u.g.: 38/83% grad: 16/84%	u.g.: 5/11% grad: 0/0%	u.g.: 3/7% grad: 3/16%	u.g.: 38/83% grad: 15/79%	u.g.: 8/17% grad: 4/21%
GMU	u.g.: 25 grad: 31	u.g.: 32/89% grad: 22/92%	u.g.: 2/6% grad: 1/4%	u.g.: 2/6% grad: 1/4%	u.g.: 32/89% grad: 22/92%	u.g.: 4/11% grad: 2/8%
JMU	u.g.: 21	u.g.: 18/95%	u.g.: 0/0%	u.g.: 1/5%	u.g.: 17/89%	u.g.: 2/11%
LC	u.g.: 20	u.g.: 29/97%	u.g.: 1/3%	u.g.: 0/0%	u.g.: 24/80%	u.g.: 6/20%
MWC	u.g.: 20	u.g.: 21/91%	u.g.: 0/0%	u.g.: 2/9%	u.g.: 18/78%	u.g.: 5/22%
NSU	u.g.: 22 grad: 28	u.g.: 1/8% grad: 5/71%	u.g.:12/92% grad: 2/29%	u.g.: 0/0% grad: 0/0%	u.g.: 11/85% grad: 6/86%	u.g.: 2/15% grad: 1/14%
ODU	u.g.: 24 grad: 30	u.g.: 29/97% grad: 53/98%	u.g.: 1/3% grad: 1/2%	u.g.: 0/0% grad: 0/0%	u.g.: 25/83% grad: 43/80%	u.g.: 5/16% grad: 11/20%
UVA	u.g.: 19 grad: 25	u.g.: 52/95% grad: 72/80%	u.g.: 1/2% grad: 1/1%	u.g.: 2/4% grad:17/19%	u.g.: 44/80% grad:79/88%	u.g.: 11/20% grad: 11/12%
VCU	u.g.: 25 grad: 31	u.g.: 28/80% grad: 8/73%	u.g.: 5/14% grad: 2/18%	u.g.: 2/6% grad: 1/9%	u.g.:28/80% grad:11/100%	u.g.: 7/20% grad: 0/0%
VMI	u.g.: 20	u.g.:4/80%	u.g.:0/0%	u.g.: 1/20	u.g.: 5/100%	u.g.: 0/0%
VPI	u.g.: 21 grad: 27	u.g.: 76/90% grad:49/100%	u.g.: 3/4% grad: 0/0%	u.g.: 5/6% grad: 0/0%	u.g.: 69/82% grad:43/88%	u.g.: 15/18% grad: 6/12%
VSU	u.g.: 22 grad: 26	u.g.: 0/0% grad: 2/18%	u.g.: 0/0% grad: 7/64%	u.g.: 4/100% grad: 2/18%	u.g.: 2/50% grad: 8/73%	u.g.: 2/50% grad: 3/27%
W&M	u.g.: 20 grad: 26	u.g.: 38/86% grad: 38/78%	u.g.: 2/4% grad: 1/2%	u.g.: 4/9% grad:10/20%	u.g.:35/80% grad: 42/86%	u.g.: 9/20% grad: 7/14%

* The undergraduate majors are upper-division only. All numbers rounded. Source: 1994 SCHEV Course Enrollment Data File.

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Consequently, the total number and percentage of physics degrees awarded to women and African-Americans in Virginia is low, even for the physical sciences.[11] The degree production for the past three years, for instance, is displayed in the following table:

TABLE 5
PHYSICS DEGREES CONFERRED BY VIRGINIA'S PUBLIC INSTITUTIONS, 1993-95

	Total	Black	Female
Baccalaureate	394	31 (8%)	78 (20%)
Master's	142	8 (6%)	20 (14%)
Doctorate	83	1 (1%)	13 (16%)

Although Virginia generally does better than the nation at recruiting women and minority students and faculty into physics, the numbers and percentages are still small.[12] The task force therefore concludes that the Virginia physics community needs to intensify its efforts to recruit and retain a diverse student body and faculty until they constitute a solid presence in that community.

This is important for several reasons. First, if the physics profession is to enhance the scientific literacy of the citizens of the United States and the Commonwealth, it is crucial that the knowledge of physics not be confined to the "majority" (actually in the minority) population. Moreover, any profession is enriched by the diversification of its practitioners, since people from different backgrounds can often bring a fresh point of view and different talents to collaborative work. But most pragmatically, the enrollment problems faced by some physics programs could be alleviated by such a significant broadening of the pool of students to whom they appeal. Nationally, fewer than a half of 1 percent (the annual average for 1989-1994 was about 4900) of bachelor's degrees are in physics. The American Institute of Physics has identified 750 undergraduate institutions that award that degree. Thus colleges have on average about 6.5 majors per year.[13] Since the Council considers unproductive any baccalaureate program that graduates on average fewer than five majors per year, it is very much in the interest of the physics programs in the state to encourage and provide opportunities for women and minority students to major in physics and thereby significantly increase their enrollments. And finally, the state benefits from the increased production of knowledge workers.

Typically, undergraduate recruitment is done at the institutional rather than at the departmental level. So in order for departments to have an effect on the recruitment of a diverse group of students likely to have an interest in physics, they need to develop effective working relationships with their admissions offices. High schools with strong science programs or above-average minority populations need to be identified, and physics faculty need to recruit actively from them students who will major in science and engineering disciplines in college. Many of the physics departments of Virginia institutions have effective outreach programs with teachers in the local schools, and these personal contacts could be valuable in identifying and nurturing qualified women and minorities.

Recommendation:

that Virginia's colleges and universities design targeted recruitment and retention strategies for minority and female undergraduate physics majors.

For example:

- Longwood College receives information from the College Board about students in the south central region who have indicated an interest in science or engineering. It then sends those students information about the Longwood program, including its 3 + 2 physics and engineering articulation agreement with Old Dominion University. Students cite the personal letters and phone calls as one of the reasons they were attracted to Longwood, which has physics enrollments two or three times those typical for institutions of its size and reportedly a hospitable environment for women and minority majors.
- One particularly successful program for the recruitment and retention of minority students is the Dozoretz National Institute for Minorities in Applied Science (DNIMAS) program at Norfolk State University. This is funded by private donations and state appropriations and provides full academic scholarships for undergraduate study in the scientific disciplines. Minority students are identified and recruited nationally. In each science department, the students have a faculty mentor who is involved in their academic program, offers career advice, and informs them of available research opportunities. In addition, the students have special housing and this, coupled with their academic program, creates a strong sense of community.

2. Graduate students

Unlike undergraduate admissions, graduate recruitment is usually done at the departmental level, either by a faculty committee responsible for all graduate affairs or by a separate graduate admissions committee. This gives departments more control over the diversity of the entering graduate class. Because no descriptions of special recruitment efforts were included in the reports to the task force, it is impossible to summarize here the efforts that programs are making. It is the task force's impression that most departments rely heavily on standardized tests, such as the Graduate Record Examinations, in sorting graduate applications. Admissions committees should be made aware that there is no agreement that standardized test results are highly correlated with research performance and success in graduate school.

The representation of minorities and women in Virginia's graduate programs is even lower than at the undergraduate level, as Table 4 showed. Every attempt should be made to actively recruit and attract qualified women and minorities into graduate programs at Virginia universities through networking and professional contacts. A department chair's commitment to increasing the fraction of women in a graduate program can be strikingly successful. For instance, under the leadership of an aggressive department chair, Howard Georgi, female representation in the 1993 incoming class to Harvard's doctoral program was significantly improved, to nearly 40 percent.

In both the nation and the Commonwealth, the graduate applicant pool includes both national and international students. Clearly foreign students, from a range of countries and ethnicities, do provide valuable cultural and racial diversity and ensure that institutions can pick, train, and possibly enrich America's workforce with the best and brightest from the entire world. But these considerations need to be balanced with the need for Virginia's institutions to focus their educational efforts on qualified Virginians and other Americans, if only because those students are most likely to work in Virginia and the United States after graduation.

As a group, the state's physics programs have done a good job of keeping their admissions decisions in balance. Of the students studying physics in Virginia at all levels, two-thirds are Virginians, just over a quarter are non-Virginian US citizens, and only seven percent are foreign residents. Only the University of Virginia and Virginia Tech have substantial numbers of foreign students at the graduate level: they constitute over a third of the UVA graduate group and just under half of Tech's. These two institutions' physics departments should continue to monitor carefully their graduate admission statistics to ensure equity and maintain an appropriate balance.

Recommendation:

> that the physics programs in the Commonwealth diversify their graduate populations, and that they not rely exclusively on foreign students to do so.

3. Faculty

The underrepresentation of minorities and women on physics faculties in the United States is significantly greater than in the other physical sciences, particularly at Ph.D-granting institutions.[14] Unless they constitute a "strong minority of at least 15 percent,"[15] women and minority faculty are apt to feel isolated. Such persons are invaluable as role models, mentors, advocates for special concerns, and "existence proofs" for students. Until qualified women and minority faculty are actively recruited by the physics community, the discipline will continue to have problems attracting, educating, and retaining large, currently uninvolved segments of the student population.

The most important factor influencing retention of women and minority students and faculty is the treatment of them in the department. Regardless of gender or ethnicity, all students should have equal access to research opportunities, be able to satisfy their intellectual curiosity, and be encouraged to develop professionally to their full potential. In 1990 the American Physical Society (APS) and the National Science Foundation (NSF) sponsored site visits aimed at improving the climate for women in physics departments. The report identifies some common problems, such as the absence of female faculty, especially those who have successfully combined a career and family; poor communication with the department chair; various forms of harassment and no effective procedures to deal with them; and the absence of other kinds of support. It also suggests many solutions, including faculty recruitment, improved communication, and a safe and supportive environment.[16] While the report focuses on women, the problems and most of the recommendations are transferable to any minority population.

Support networks help improve the academic and social climate for women and minorities. As we have mentioned, the Society of Physics Students (SPS) can be very effective in connecting undergraduate students to each other, the faculty, the department, and the APS. At several institutions graduate students and/or faculty women have organized "women in physics" or campuswide "women in science" groups or established chapters of national organizations such as the Association for Women in Science (AWIS) or the Women in Science and Engineering (WISE). These have been most successful when they involve women at every level -- undergraduate, graduate and faculty. They provide a support network and a forum for discussing professional concerns of particular relevance to women. The solidarity and sense of community help improve the climate in physics and integrate women into the profession.

Recommendation:

that the physics programs in Virginia actively recruit and remove all barriers to the retention and promotion of qualified women and minority faculty.

For example:

- The University of Virginia was one of five departments and the only one in Virginia that was included in the original APS/NSF site visits, thus demonstrating national leadership and a commitment to improve the climate for women in physics. The report from the site visit identified the lack of women faculty as a major problem. Many of the suggestions offered by the review team have been implemented, and these have resulted in a significant improvement of the climate for all members of that physics department. The recent recruitment by the engineering school of astronaut Kathryn Thornton, herself a UVA physics graduate, suggests the ways in which physics departments can grow their own women and minority faculty members.
- The State Council of Higher Education has a number of programs designed to increase minority representation in higher education. Among those that are most likely to be useful to physics programs and in which they should become involved on their campuses are the Summer Program for Undergraduate Virginians, designed to inform undergraduate other-race Virginians about graduate education and allow them to experience it during a summer session, and three graduate fellowship programs: the State Graduate Deans' Fellowship Program, the Commonwealth Graduate Fellowship Program, and the Southern Regional Education Board (SREB) Doctoral Scholars Program, all designed to increase the number of other-race students enrolled in graduate programs who will subsequently undertake academic careers.

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- The NSF's Alliances for Minority Participation (AMP) takes as its aim "to strengthen and encourage the production of baccalaureate degrees earned by students from minority groups underrepresented in science and engineering." The NSF has allocated more than $27 million in 1997 for these activities.[17]

Part VII: Facilities

In order to provide high-quality instruction in physics, it is essential that well-equipped modern laboratories, quality teaching space, adequate storage space, computers, library resources, and a shop for repairing and fabricating equipment (staffed by faculty, technicians, and student project assistants). Departmental facilities should be consistent with their programs' goals, mission and curricula.

According to information provided in the self-study reports, the amount of assignable space per teaching faculty member for the physics departments varied up to almost threefold within the same institutional type. At the four Ph.D.-granting institutions, the amount of space dedicated to the physics departments varied from 35,000 square feet to 91,000 square feet, with three of them between 35,000 square feet and almost 42,000 square feet. This comes to between about 1400 and 2600 assignable square feet per teaching faculty member. For those institutions whose highest degree level in physics is the master's, the total space allocation varied from about 6800 square feet to 17,000 square feet, or from about 950 to almost 1700 square feet per teaching faculty member. The space allocation for departments offering Bachelor of Science level programs varied from almost 6000 square feet to almost 12,600 square feet, or from approximately 1250 to 5200 square feet per teaching faculty member. There are reasons for the differences, including variations in what is counted in that space, the amount of sponsored research, and the numbers of staff and faculty who are funded by those grants. But institutions at the far extremes might want to review their space allocations.

Two institutions, having done so, are in the process of making major changes in their facilities: Mary Washington College is currently planning a new facility, and a new building to house portions of the departments of physics and oceanography is presently being constructed at Old Dominion University. This new building will have 45,000 square feet for the department of physics, and it will replace the space that the department now occupies in another building.

Several departments have expanded their research facilities by forming partnerships or linkages with research centers and scientific laboratories located both in and outside of the Commonwealth. For example, the Tidewater universities all have active involvements with the nearby Jefferson Lab and NASA Langley Research Center. Virginia State University has a particularly close relationship with the Tri-University Meson Facility (TRIUMF) in Vancouver, British Columbia, Canada. As a result of these linkages, students and faculty at these universities have access to the excellent research opportunities available at these facilities. This kind of cooperation will become increasingly important as the National Science Foundation gets out of the business of modernizing facilities under the Academic Research Infrastructure Program. The 1997 NSF budget request follows the Vice President's National Performance Review's recommendation that responsibility for "the upgrading and renovating of university laboratories" be turned over to the states, local communities, and institutions.[18]

Although all institutions are directly or indirectly accessing a supercomputer for computational purposes, other computational equipment and facilities vary widely among the institutions. Physics students and faculty members at the institutions also have varying capabilities to access the resources available on the Internet and the World Wide Web for instructional and research activities. The 1996 General Assembly made a generous allocation to the colleges and universities as part of the Higher Education Equipment Trust Fund (see the "Technology Appropriation" line in Table 6 in the next section) to help them upgrade their computer and telecommunications capacities. In addition to supporting their academic programs, a few institutions are using their computational resources to provide services to local communities.

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Part VIII: The Costs and Benefits of Physics Programs

1. Costs and benefits

Like any other program at a college or university, the physics program incurs costs and provides benefits for the students, the university, the community, and the advancement of disciplinary knowledge. Many of the benefits and even the costs are difficult to measure because of insufficient data. They are especially difficult to compare, because of the noncomparability of the data that **are** available. Moreover, despite often feeling underappreciated on the contributory side and undersupported on the cost side, most faculty have been reluctant to do a serious cost/benefit analysis of their work. This problem is not confined to physics programs. But in these tight fiscal times, given the relatively high costs of and few majors in physics programs, it is especially in their interest to have complete and reliable data with which to make a reasoned case for the resources that they need and the contributions that they make. It is also critical for physics departments to understand how they fit into the broader college or university picture of program costs, so that they can respond reasonably to administrative decisions.

The cost data submitted by the institutions represent such a wide range of reporting formats and specificity, and they differ enough from those obtained through a May 1996 request by the American Physical Society on our behalf, that few reliable assertions or comparisons can profitably be made, beyond the one that the cost-to-student-credit-hour ratio is greater (roughly one and a half times the average in those institutions that made the calculation) than that of the average program. This leads to the

Recommendation:

> that the physics programs in Virginia, with the aid of their institutional fiscal officers, regularly track their costs and contributions, and that those data be made available to all members of the department. The State Council of Higher Education should develop a uniform cost/benefit analysis model to facilitate this process. Deans and provosts should collect comparable data about all programs and make them generally available, in order to promote responsible dialogue about the distribution of resources and the expectations that they have of each department.

2. External support

Because of their relatively modest enrollment in the major, if not in their service courses, physics programs cannot generally point to the production of large numbers of student credit hours as a major benefit that they provide to the institution. However, they are often among the top departments in obtaining external grant support, with its benefit of overhead return to the institution. The degree to which this is possible varies, of course, by institutional type. But even programs in predominately teaching institutions can seek external support for work connected to their teaching missions, including student support, visiting lecturers, teaching equipment, work with the local schools, or curricular innovations. To give only a few examples, the Virginia Space Grant Consortium awards undergraduate research scholarships and graduate fellowships for students whose work is related to aerospace science. The American Physical Society provides a list of women physicists who are willing to come to campus for lectures. The Department of Education administers the Eisenhower Program, through which colleges bring up to date in their disciplines high-school teachers who teach science and mathematics. Finally, the National Science Foundation's recent presentation to the 104th Congress's Second Session stressed that "in a set of activities ranging from Research Experiences for Undergraduates through comprehensive undergraduate education reform, graduate traineeships, and awards to new investigators with both research and education objectives, NSF emphasizes the ties between research and education and moves to reinforce them."[19]

With federal research support flat or even declining, industrial support and research related to local economic development should provide an increasing base of support for physics-related research. Benefits that such support brings the institution in addition to money include the development of additional career contacts and paths for students, the disciplinary and community recognition that first-rate research brings to the institution, and some overhead return to further support the institution (a portion of which should be returned to the department to encourage future entrepreneurial activities).

Therefore the task force makes the following

Recommendation:

that physics programs develop strategies to obtain or increase external funding, including funds for the teaching mission and industrial support for research.

3. Equipment

Physics relies very heavily on laboratory and computing equipment for research (generally paid for by grant funds) and teaching (for which the Higher Education Equipment Trust Fund [HEETF] is the major resource). The Higher Education Equipment Trust Fund has been extremely beneficial to all equipment-intensive disciplines in the state. But when the task force visiting teams asked departments about the HEETF funds available, most did not know the amount of these funds that had been awarded to the institution, much less how and what amount their administrations had decided to allocate funds to the department. Some departments were not even prepared -- for instance with lists of needed equipment -- to spend the money should it become available. The 1996 General Assembly made a significant investment in equipment, including sums to cover equipment deficiencies and obsolescence and a special appropriation for teaching technology and some aspects of infrastructure development, as Table 6 demonstrates. Departments will need to be prepared to act quickly in order to spend this money effectively.

TABLE 6
HIGHER EDUCATION EQUIPMENT TRUST FUND APPROPRIATIONS

Institutions	1996-97 Technology Appropriation	Obsolescence & Deficiency	Total	1997-98 Technology Appropriation	Obsolescence & Deficiency	Total	1996-98 Technology Appropriation	Obsolescence & Deficiency	Total
GMU	$1,791,007	$3,394,183	$5,185,190	$1,791,006	$3,394,183	$5,185,189	$3,582,013	$6,788,366	$10,370,379
ODU	$1,482,882	$1,065,378	$2,548,260	$1,482,881	$1,065,378	$2,548,259	$2,965,763	$2,130,756	$5,096,519
UVA	$2,495,435	$3,491,744	$5,987,179	$2,495,434	$3,491,744	$5,987,178	$4,990,869	$6,983,488	$11,974,357
VCU	$2,495,224	$1,676,562	$4,171,786	$2,495,223	$1,676,562	$4,171,785	$4,990,447	$3,353,124	$8,343,571
VPI	$2,899,712	$4,658,488	$7,558,200	$2,899,711	$4,658,488	$7,558,199	$5,799,423	$9,316,976	$15,116,399
W&M	$997,754	$319,258	$1,317,012	$997,754	$319,258	$1,317,012	$1,995,508	$638,516	$2,634,024
CNU	$522,855	$5,091	$527,946	$522,854	$5,091	$527,945	$1,045,709	$10,182	$1,055,891
CVC	$199,928	$0	$199,928	$199,927	$0	$199,927	$399,855	$0	$399,855
JMU	$940,199	$217,682	$1,157,881	$940,199	$217,682	$1,157,881	$1,880,398	$435,364	$2,315,762
LC	$262,255	$0	$262,255	$262,255	$0	$262,255	$524,510	$0	$524,510
MWC	$569,713	$96,596	$666,309	$569,712	$96,596	$666,308	$1,139,425	$193,192	$1,332,617
NSU	$1,146,657	$0	$1,146,657	$1,146,657	$0	$1,146,657	$2,293,314	$0	$2,293,314
RU	$840,044	$125,137	$965,181	$840,044	$125,137	$965,181	$1,680,088	$250,274	$1,930,362
VMI	$250,579	$88,348	$338,927	$250,579	$88,348	$338,927	$501,158	$176,696	$677,854
VSU	$789,712	$236,638	$1,026,350	$789,712	$236,638	$1,026,350	$1,579,424	$473,276	$2,052,700
RBC	$146,051	$29,973	$176,024	$146,051	$29,972	$176,023	$292,102	$59,945	$352,047
VCCS	$6,414,919	$0	$6,414,919	$6,414,918	$0	$6,414,918	$12,829,837	$0	$12,829,837
TOTAL	$24,244,926	$15,405,078	$39,650,004	$24,244,917	$15,405,077	$39,649,994	$48,489,843	$30,810,155	$79,299,998

Recommendations:

that central administrations allocate equipment money as quickly as possible, that the departments make an effort to keep informed about the institutional equipment allocation and what their share of it will be as soon as is practicable, and that the departments provide their deans with regularly updated lists of equipment that they need and the benefits they will provide the program. All departmental faculty members should contribute to the development of this list, which should be congruent with a rolling departmental five-year plan for each program's curricular and research development, adjusted as needed according to what the department learns from its student assessment and graduate tracking programs.

Part IX: Partnerships

In Part III of this report, the task force suggested ways in which departments could cooperate in offering students a wider range of learning opportunities. The same kinds of cooperation could also strengthen their research and the learning that occurs when undergraduate and graduate students engage in advanced research projects.

Through cooperation and sharing resources, Virginia's physics (and other scientific and engineering departments) could, with existing state resources, have much greater effect on research and education. Simultaneously, they would become more attractive candidates for state, federal, and private support for those activities. For instance, NSF is proposing to increase its support for its Grant Opportunities for Academic Liaison with Industry (GOALI) program by more than 40 percent in 1997, to almost $18 million.[20] Subcritical research groups or individual researchers requiring access to expensive instrumentation or unique facilities have much to gain by multi-institutional collaboration. The task force therefore makes the following

Recommendation:

> that such research collaborations among Virginia's physics departments be encouraged and supported.

For example:

- The Virginia Physics Consortium (VPC) was organized in 1994 to encourage collaborative activities among the Virginia university graduate physics departments, with an initial focus on nuclear physics research opportunities at the Jefferson Laboratory. The VPC has expanded its charter to take advantage of the new Free Electron Laser User Facility, presently under construction at Jefferson Lab, with initial operations scheduled for 1998. The VPC is exploring a number of specific mechanisms for encouraging cooperation among Virginia's universities, including seed funding for multi-institution research proposals, collaborative course development and teaching activities, graduate fellowships, student internships, and faculty sabbaticals.
- Existing collaborations involving physics departments have already formed around the NASA Langley Research Center in Hampton in aeronautics and atmospheric sciences and the Jefferson Lab in both nuclear physics and laser physics.
- The Virginia Microelectronics Consortium (VMEC) was formed by Virginia's engineering schools to take advantage of the impending investment of $6 billion in microelectronic fabrication plants in Virginia by Motorola, IBM, Toshiba, and Siemens. Electrical engineering departments will take the lead in this consortium, but there will be significant opportunities for Virginia's physics departments to develop relevant courses and research programs in plasma processing, materials physics, microelectronic device physics, and modeling.

- A number of initiatives are forming in the Commonwealth to take advantage of the ability to link universities to remote high-performance computers for advanced modeling and computational physics and to link to remote data acquisition and control of centralized research facilities (such as light sources, telescopes, and particle accelerators). The Southeastern University Research Association(SURA), which built one of the original high-capacity computer networks linking the Virginia universities with other universities in the Southeast (SURANET), is proposing an upgrade to state-of-the-art networking capability (OC-3 trunk lines) and specific mechanisms for remote operation and data logging on experimental equipment at the Jefferson Lab, other particle accelerators and light sources operated by DOE, and telescopes operated by the NSF and university consortia. Theoretical and computational physicists can take advantage of this pooling of resources for centralized operation and maintenance of expensive high performance computing hardware and software.
- The Applied Research Center in Newport News is a partnership among the City of Newport News, Jefferson Laboratory, Old Dominion University, Christopher Newport University and the College of William and Mary. It was formed to sponsor applied research and development opportunities created by the technology generated at the Jefferson Lab. Physics, applied science, and engineering faculty at all three academic institutions have solicited and received both Commonwealth and private funding as a result of the partners' stated goals to collaborate, leverage existing resources, and focus on opportunities arising from the Jefferson Lab's Free Electron Laser Facility. The City of Newport News broke ground in May 1996 for a 120,000-square-foot building on the Jefferson Lab site to house the Center's activities. The industrial research park associate with Virginia Tech is a similar partnership.

The task force encourages the faculty of the Commonwealth's physics departments to take advantage of the interdisciplinary research centers that have already been established, attained critical mass, and earned a noteworthy reputation among peers. The Commonwealth already has a number of such centers that have been initiated and nurtured by Commonwealth (through the Center for Innovative Technology, or CIT) and federal (usually NSF) funds. Often these centers have an engineering focus, such as the NSF-sponsored center for polymer science and the CIT center for photonics at Virginia Tech. However, there is mutual benefit in physics department participation in such centers: physicists can add scientific breadth to the center's activities while developing an applied physics focus for faculty research and student training.

Why should an individual or group of physics faculty members participate in any of the partnerships or alliances cited as examples in this report? The obvious benefits come from the strength of the partnership in attracting and using resources more effectively than can small groups or individuals. Partnerships and shared ventures are particularly valuable models for research, development, and the associated college-level training because of the expense of these ventures and the stagnation of state and federal funding for these activities. The task force encourages the Commonwealth's academic institutions and the legislature to recognize the inherent and economic value of such partnerships and to support their growth.

ENDNOTES

1. Marvin L. Goldberger *et al*, eds, *Research-Doctorate Programs in the United States: Continuity and Change* (Washington, D.C.: National Academy Press, 1995), p. 22.

2. Laura O. Palmer, "An Interview with Jan Civian, Project Director [of the Pathways for Women in the Sciences Project, Part II]," *Research Report*, XV no. 2 (Spring 1996), 3.

3. American Institution of Physics (AIP), *Enrollment and Degrees Report*, AIP Pub. No. R-151.32 (January 1996), pp. 1 & 3.

4. Colleen Cordes and Paulette V. Walker, "Ability to Win Grants Increasingly Dictates Clout of Departments Within Universities," *Chronicle of Higher Education*, 14 June 1996, p. A14. Much of this shift is due to the cancellation of big national facilities such as the Superconducting Supercollider and the move into a new era of international cooperation in developing such big projects.

5. AIP, pp. 1 & 6.

6. Bonnie Newman Stanley, "Diplomas Again Lead to Incomes, " *Richmond Times-Dispatch*, 2 June 1966.

7. Amy Pendergast, ed., *The Liberal Art of Science* (Washington, DC: American Association for the Advancement of Science, 1990), p. xi.

8. *The Dissolution of General Education: 1914-1993* (Princeton: National Association of Scholars, 1996), p. 53.

9. "What Research Says About Improving Undergraduate Education: Twelve Attributes of Good Practice," *AAHE Bulletin*, April 1996. The twelve attributes are:

   i. high expectations
   ii. respect for diverse talents and learning styles
   iii. emphasis on the early years of study
   iv. coherence in learning
   v. synthesizing experiences
   vi. ongoing practice of learned skills
   vii. integrating education and experience
   viii. active learning
   ix. assessment and prompt feedback
   x. collaboration
   xi. adequate time on task
   xii. out-of-class contact with faculty.

10. The confidence of high-school students who excel in mathematics and science extends to those in low-income groups, who plan to attend four-year colleges in greater numbers than their peers from the same income group and at about the same rate as that for all SAT takers. See Jacqueline E. King, *The Decision to Go to College: Attitudes and Experiences Associated with College Attendance Among Low-Income Students* (Washington, DC: College Board, 1996).

11. In 1994, the comparable figures in Virginia for all the physical sciences, including physics, were that women receive 39 percent of the bachelor's degrees and 29 percent of the master's and Ph.D.s; blacks are awarded 8 percent of the bachelor's degrees, 6 percent of the master's, and 3 percent of the doctorates. This compares favorably with the 1995 national figure for doctorates in the physical sciences earned by women, which the National Research Council puts at 22 percent, and by blacks, which was at 1.3 percent (Denise K. Magner, "More Black Ph.D.'s," *Chronicle of Higher Education*, 14 June 1996, p. A26).

12. According to unpublished data of the American Physical Society, the comparable national figures for physics degrees granted are as follows:

	Total	Black	Female
Baccalaureate	4615	180 (4%)	792 (17%)
Master's *	822	21 (2%)	153 (14%)
Doctorate	1481	11 (1%)	184 (12%)

* The master's figures cannot be compared to Virginia's, since they include only individuals with professional but not terminal master's degrees.

According to the same data source, the national figures on faculty are even more dismal: less than 2 percent of national physics faculty are black and 6 percent are female, compared to Virginia's 5 percent black and 10 percent female.

13. AIP, p. 12. At the baccalaureate-only institutions, the numbers were even lower: between 1989-94 slightly more than 2000 degrees were awarded by about 490 institutions, for an average of 4.1 per institution per year.

14. See Mildred S. Dresselhaus *et al*, *Improving the Climate for Women in Physics Departments* (American Physical Society, n.d.), p. 4.

15. Etzkowitz et al, "The Paradox of Critical Mass for Women in Science," *Science*, *266* (7 October 1994), 51.

16. Dresselhaus, pp. 10-11.

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17. Julia A. Moore and Joel M. Widder, *Congressional Report: A Report on Selected Congressional Activities Prepared by the National Science Foundation's Office of Legislative and Public Affairs,* NSB 96-57 (Washington, D.C: NSF, Sept 95- April 96), p.4.

18. *Ibid.*, p. 3.

19. *Ibid.*, p. 4.

20. *Ibid.*, p. 4.

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