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ABSTRACT

This is a report of the National Advisory Groups of Sigma Xi to explore the nature and quality of undergraduate education in science, mathematics, and engineering and to identify the significant topics and issues that should be addressed in charting a policy for undergraduate education. The topics identified are: (1) "Quality of Instruction" discussing hands-on experience, reward systems, and use of teaching assistants; (2) "Quality of Curriculum" suggesting changes of entry-level courses; (3) "Quality of the Human Environment" emphasizing personal relationships among students, faculty, and administrative personnel; (4) "Quality of the Physical Environment" discussing laboratory experience and educational technology; (5) "Accessibility and Flexibility of Curricula Essential for Student Mobility"; (6) "Attitudes and Perceptions of Students, Faculties, Administrations and the Public"; and (7) "Promises and Special Needs of Traditionally Underrepresented Groups in Science, Mathematics and Engineering." In this report, the last three are interwoven into the discussion of the first four. After discussing the potential of undergraduate education, initiatives to Congress and the National Science Foundation are described. List of participants, an entry-level course sequence, and the keynote address on profile of undergraduate are appended. (YP)

AN EXPLORATION OF THE NATURE AND QUALITY OF UNDERGRADUATE EDUCATION IN SCIENCE, MATHEMATICS AND ENGINEERING

A REPORT OF THE NATIONAL ADVISORY GROUP OF SIGMA XI, THE SCIENTIFIC RESEARCH SOCIETY

Supported by:
The National Science Foundation
and
The Johnson Foundation

Wingspread
Racine, Wisconsin
January 23 - 26, 1989

The National Advisory Group of Sigma Xi, The Scientific Research Society, met at Wingspread in Racine, Wisconsin, January 23 - 26, 1989 to identify fundamental topics and issues that should be addressed in charting policy for undergraduate education in science, mathematics and engineering. Further information about the meeting and the participants is given in Appendices One and Two.

The workshop and this report were developed under a grant funded by the Division of Undergraduate Science, Engineering and Mathematics Education of the Directorate for Science and Engineering Education of the National Science Foundation.

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28 April 1989

Dr. Bassam Z. Shakhashiri
Assistant Director
Science and Engineering Education
National Science Foundation
Washington, D.C. 20550

Dear Dr. Shakhashiri:

We are pleased to transmit to you and to our colleagues in the research and academic communities the report developed by our National Advisory Group convened under the support from the Foundation, with the cooperation of The Johnson Foundation.

As the Scientific Research Society, Sigma Xi has a special responsibility to ensure a dynamic and creative growth in the research community. We share the national concern over the dwindling number of entrants into professional careers in science, mathematics and engineering. In addition, we have a deep conviction that a flourishing research enterprise supportive of national goals requires an informed perception of its fundamental characteristics on the part of the general public.

We view the nature and quality of undergraduate education in science, mathematics and engineering as a particularly vital element in attracting young men and women into the field of teaching and research and in enhancing the scientific literacy of the general public.

Our National Advisory Group explored this issue in detail at the Wingspread Meeting in Racine, Wisconsin, for three days last January. We appreciated especially that challenge you set before us in our opening session.

In the report that follows, Dr. Anna J. Harrison has summarized the results of a lively discussion among informed individuals with a deep commitment to a topic they were addressing. We believe that the findings will be useful to you and Dr. Robert Watson in discharging your major responsibilities, to the array of educational institutions in the nation, to both public and private institutions that fund educational research, and helpful to the 110,000 members of Sigma Xi in over 500 chapters and clubs. We hope these views provide a stimulus to action on the part of all.

Sigma Xi will pursue these issues in a series of four special sessions during our Annual Meeting in Denver, Colorado, October 26-29, 1989. We anticipate a deepening and widening of the discussion that began so auspiciously at Wingspread. We look forward to further discussions with you and with other leaders from the academic, research, governmental, and private communities.

Sincerely yours,

Thomas F. Malone
President

QUOTATIONS FROM THE KEYNOTE ADDRESS

From:
A Profile of Undergraduates in the Sciences

by:
Kenneth C. Green
Higher Education Research Institute
University of California, Los Angeles

"Freshmen interest in fundamental undergraduate science majors has dropped dramatically — by almost half — over the past 23 years."

"Freshman interest in technology careers has experienced a dramatic decline in just the past six years. Between 1982 and 1988, the proportion of freshmen planning to pursue careers as engineers fell by almost one-quarter, the proportion of freshmen planning to pursue courses as computer professionals has plummeted, falling by nearly three-fourths in just six years."

"Every year tens of thousands of academically-able students enter college planning to pursue science majors. Yet more than half of these students change their intended major for other, non-science fields. Moreover, the high defection rates for aspiring science majors are not offset by recruits from other (non-science) fields."

"The disciplinary-training of secondary school science teachers has declined dramatically over the past two decades. Today very few aspiring science and math majors plan to pursue careers as high school teachers."

"... if undergraduate science departments were run like for-profit business — that is, without substantial institutional subsidy — most programs might be bankrupt, largely because of their capacity (some might say basic inclination) to 'alienate' potential clients."

(The complete text of the keynote address is provided in Appendix 4 of this volume.)

FINDINGS IN BRIEF

Charge to the National Advisory Group

The specific charges to the National Advisory Group (Appendices 1 and 2) were:

1) To explore the nature and quality of undergraduate education in science, mathematics and engineering; and

2) To identify the significant topics and issues that should be addressed in charting policy for undergraduate education in science, mathematics and engineering.

The topics identified as most significant (seven in number) are presented briefly here in the context of the culture of the nation, and the subcultures of undergraduate students, academic institutions, and the scientific community including scientists, mathematicians, engineers, and their professional societies. The perceptions and the values of these cultures provide the infrastructure within which undergraduate education in science, mathematics and engineering proceeds.

Quality of Instruction (page 6)

Fundamental Topic One

Many scientists, mathematicians and engineers like to teach and are capable of becoming superb teachers sharing their knowledge and enthusiasm with students. Relatively few scientists, mathematicians and engineers have the good fortune to be allowed to devote a significant portion of their time, energy and creativity to excellence in teaching without accepting significant psychological and monetary penalties. Undergraduate education is trapped in an infrastructure that rewards those who devote their resources to research and denies those same rewards to those who devote a significant portion of their resources to fulfilling the mission of undergraduate programs — to encourage and enable undergraduate students to achieve. The practices of many segments of society (including the research community, college and university administrations, state and federal governments and their agencies, and private foundations that fund research) have created and reinforced the value system that produced and sustains this dichotomy.

Quality of Curriculum (page 8)

Fundamental Topic Two

The student perception of the undergraduate curriculum in science, mathematics and engineering and the faculty perception of that same curriculum are by no means congruent. Many freshmen view entry-level courses in science, mathematics and engineering as inaccessible — or if accessible, unrewarding to them. Many freshmen who come to college well prepared and expecting to major in science, mathematics or engineering disappear after the freshman year even though they may have done very well academically in advanced placement courses or honors courses in college. The National Advisory Group identified entry-level courses in science, mathematics and engineering as "watersheds" that determine both the place of science, mathematics and engineering in the lives of those who go to college, and the vitality of undergraduate programs in science, mathematics and engineering in colleges and universities. A great deal of attention was given to an exploration of the characteristics of more appropriate entry-level courses for major sequences, and also entry- level courses for general education sequences — courses that would be more interesting and more rewarding to students.

Quality of the Human Environment (page 15)

Fundamental Topic Three

Large classes impose student/faculty ratios that often make the faculty inaccessible to all but a few students and, at best, students view the human environment as impersonal. The common practice of using entry-level courses as barriers to protect more advanced courses from all except the most able and the most committed still persists and, at worst, students view these classroom environments as destructive and hostile. A positive and supportive human environment has value to all students and is particularly valuable to women, minorities and the physically disabled. Many of these students still bear the burden of the public assessment that science, mathematics and engineering are beyond their grasp.

The success of many liberal arts colleges in encouraging and enabling undergraduates to pursue graduate study in science and mathematics may lie in a rich human support system made available to their undergraduates.

Quality of the Physical Environment (page 18)

Fundamental Topic Four

With full recognition of the value to undergraduate education of access to adequate library holdings, laboratory facilities and levels of instrumentation, the National Advisory Group focused its attention on the aspects of the experience within that physical environment that are truly educational to students. High value was placed upon the student having hands-on experience with the investigation of phenomena. Through this experience, the student has experience with critical thinking, planning, analysis and synthesis and the opportunity to discover the integrity of data, the uncertainty of measurements and, through these, the development of understanding of the powers and limitations of science and engineering. In particular, the National Advisory Group took a very strong position that contemporary educational technology be used to facilitate good teaching — but not as a substitute for the teacher. Computer simulations, appropriately used, can facilitate good teaching. However, to use computer simulations as a substitute for hands-on experience with the investigation of phenomena was judged to be educationally unsound.

Accessibility and Flexibility of Curricula Essential for Student Mobility

Fundamental Topic Five

Faculty and student may view an undergraduate major in a discipline differently. To the faculty the major may be a carefully sequenced program of courses designed to deliver the major into graduate study or to launch a professional career in engineering with the best possible preparation in that discipline. To the student, a tightly sequenced major in a discipline may be perceived as a one-way express road with an entrance ramp in the freshman year and an exit ramp at the completion of the major in the senior year — no interchanges along the way. The student who wants to participate in charting his or her undergraduate education on the basis of experience and developing interests needs a map with interchanges to major sequences in other disciplines.If interchanges between disciplines do not exist, attention should be given to creating them. Accessibility to upper level courses in one discipline can indeed be based upon experience and maturity acquired in other disciplines and through other experiences. The student who is adventurous in exploring other disciplines as an undergraduate may be the graduate who is attracted to interdisciplinary areas in his or her career.

Attitudes and Perceptions of Students, Faculties, Administrations and the Public

Fundamental Topic Six

In the presentation of the preceding five significant topics, issues related to attitudes and perceptions have arisen repeatedly. In addressing these topics and some of their concomitant issues, it becomes evident that attitudes and perceptions are in themselves significant topics. In charting policy for undergraduate education in science, mathematics and engineering, bringing about changes in attitudes and perceptions must be a part of any effective policy.

Promises and Special Needs of Traditionally Under-Represented Groups in Science, Mathematics and Engineering

Fundamental Topic Seven

Women, minorities and the physically disabled are emerging as significant talent pools in science, mathematics and engineering. (A third of the students entering Spelman College, historically a college for Black women, now expect to major in science, mathematics and engineering.) And there is every reason to expect the significance of these talent pools to expand. This places the promises and special needs of these traditionally underrepresented groups high on any list of significant topics to be addressed in charting policy for undergraduate education in science, mathematics and engineering.

The seven significant topics delineated above are interrelated and many are interdependent. In this report the last three are interwoven into the discussion of the first four, just as they are in life.

Potential of Undergraduate Education

Undergraduate education in science, mathematics and engineering has the potential to be the most effective leverage point in improving the quality of education in science, mathematics and engineering at all levels. Those who teach at the undergraduate level can have the rich academic backgrounds and the close ties with current research to understand what modern science, mathematics and engineering are about and, consequently, meet the needs of: 1) those preparing for careers in school (K-12) teaching; 2) those preparing to enter graduate and professional programs in science, mathematics and engineering; 3) those preparing for careers such as law, management and communications; and 4) all those preparing for participation in the democratic processes of our technological society. For endeavors of such significance, the magnitude of the task can not be an excuse for inaction. A multiplicity of achievable steps, many small — some large, taken together can have a strong positive impact on the nature and quality of undergraduate education in science, mathematics and engineering.

The fulfillment of the missions of undergraduate education in science, mathematics and engineering requires the participation and leadership of many communities, organizations and institutions. Some of that participation and leadership is arising within foundations and industries, governments and government agencies, and the community of scientists, mathematicians and engineers (including the professional societies) as well as within the colleges and universities.

Initiatives Appropriate to Congress and the NSF Directorate for Science and Engineering Education

The Sigma Xi National Advisory Group on undergraduate education in science, mathematics and engineering strongly urges Congress and the NSF Directorate for Science and Engineering Education to facilitate:

- Open and forthright discussion and evaluation of the factors that make the reward system for excellence in undergraduate teaching non-competitive with the reward systems for excellence in other professional activities of scientists, mathematicians and engineers;

- Scholarly research related to learning at the undergraduate level;

- Development of more appropriate entry-level undergraduate courses for 1) majors and 2) general students in science, mathematics and engineering;

- Enhancement of the quality, breadth and contemporary nature of upper-level courses in science, mathematics and engineering;

- Development of process-oriented laboratories for all students at all levels in science, mathematics and engineering;

- Participation of majors in science, mathematics and engineering in student research;

- Entry and sustained professional development of women, underrepresented minorities and physically disabled in science, mathematics and engineering; and

- Exchange of information among those developing innovative undergraduate curricula — particularly entry-level courses

Government agencies, foundations, industries, and professional organizations can provide essential help. It is, however, academic institutions, their departments and their faculties that must initiate and bring about change. To bring about fundamental changes is difficult, slow and expensive. There are no quick fixes. The future justifies the investment.

TABLE
OF
CONTENTS

1

MISSIONS OF UNDERGRADUATE EDUCATION IN SCIENCE, MATHEMATICS AND ENGINEERING

Missions

Undergraduate programs exist in order to provide environments that encourage and enable students to accomplish something. These "somethings" are the missions of the programs. Just exactly what these missions are depends upon the perceptions of academic administrators and departmental faculty members of factors such as 1) the needs and goals of students and 2) the needs and goals of society.

Undergraduate missions of departments of science, mathematics and engineering include encouraging and enabling undergraduate students:

1) to pursue careers:
  a) in science, mathematics, engineering and related endeavors;
  b) in school (K-12) science and mathematics education; and
  c) in scientific and technological aspects of law, mass communications and management;

2) to discover the nature of science, mathematics and engineering;

3) to discover the aesthetic and human dimensions of science, mathematics, engineering and technology (the order and beauty of many natural systems and many products of technology, the ingenuity of the human mind in creating models to rationalize the properties of systems and in creating technological options for the production of goods and services and the resolution of societal issues); and

4) to become informed participants in the democratic processes through which value-laden issues involving science, mathematics, engineering and technology are resolved.

Practices in science, engineering and mathematics education indicate that those who develop curricula and teaching materials, those who teach, and those who structure examinations may at times lose track of what science, engineering and mathematics are.

The Nature of Science

Science is a process of investigating phenomena — physical, biological, behavioral, social, economic and political phenomena.

Process, as used here, is an inclusive term encompassing:

- The selection of the phenomenon to be investigated,
- The selection or development of an appropriate methodology,
- The selection or development of appropriate instrumentation,
- The delineation of an appropriate protocol (procedure),
- The execution of the protocol and the collection of data,
- The reduction of data and the assessment of the uncertainty of the results,
- The correlation of the results with existing knowledge, and
- The analysis of the theoretical implications of the results.

Any phenomenon for which methodology and instrumentation can be developed and validated is within the domain of science (the process). Science as a process of investigation of phenomena is frequently alluded to as "science as a way of knowing."

The Nature of Scientific Knowledge

The legacy of science, the process of investigation of phenomena, is a body of scientific knowledge consisting of:

- A data base,
- An array of methodologies,
- An array of concepts, and
- An array of theories and models.

Many issues concerning curricula have to do with the relative weighting given in various courses to 1) the process of investigation of phenomena, and 2) the body of scientific knowledge and, within the time allotted to the body of scientific knowledge, the relative weighting given to a) data bases, b) methodologies, c) concepts and d) theories and models.

The Nature of Engineering

Similarly, engineering is the process of investigating how to solve problems such as making a plastic cup that meets delineated specifications, or designing and building a communication satellite that meets delineated performance requirements, or designing and instituting police services that meet specified needs of a given community. In each case the first step in the process is accepting the problem and the final step is validating that the product, process or service meets all of the specifications and performs the required function.

The Nature of Engineering Knowledge

The legacy of engineering, the process of investigating how to solve engineering problems, is a body of engineering knowledge consisting of a data base, an array of methodologies, an array of concepts, and an array of theories and models.

Although there are many parallels between science and engineering, the goals of science and engineering are fundamentally different. Science is the process of investigating phenomena with the goal of creating understanding: engineering is the process of problem-solving with the goal of creating a product, device, facility or system, subject to constraints such as economics, safety, aesthetics, and environmental impact.

The Nature of Mathematics

Tremendous changes during the past twenty-five years in how mathematics is done have imposed upon mathematicians the necessity to rethink the nature and the definition of mathematical science. Today, mathematical science is defined loosely as the science of patterns. The role of patterns in mathematics is by no means new. Newton perceived patterns in astronomical data, formulated principles consistent with those patterns and used those principles to deduce other patterns, some known and some unknown, of behavior for planetary systems. What is new is a millionfold expansion in the number of patterns investigated by mathematicians brought about through the use of computers. The new definition 1) subsumes and unites many aspects of statistical sciences, core (pure) mathematics, and applied mathematics, 2) acknowledges the dependency of mathematics on the data bases of science and engineering, and 3) delineates a leadership role of mathematics in the evolution of science and engineering. The symbiosis of mathematics, science and engineering becomes increasingly apparent. The computer-assisted tomography (CAT) scanner is just one techno-

Symbiosis of Science, Mathematics and Engineering

logical product derived through this synergism.

Applications based upon comparisons of fit of patterns with observations of natural phenomena are now central to many scientific investigations and technological developments. Dramatic uses of concepts from pure mathematics in unexpected applications are occurring with increasing frequency. Even so, the symbiosis of mathematics, science and engineering is not necessarily effectively exploited. Many scientists and engineers have not explored mathematics beyond the calculus, analysis and differential equations taught to them as students and, in many institutions, modernization of curriculum has been repressed by inertia and accreditation systems.

Failure of Undergraduate Education to Fulfill Missions

Evidence mounts that undergraduate education in science, mathematics, and engineering is not fulfilling its missions. A high proportion of freshmen who enter college planning to major in these fields either change their minds during entry-level courses, drop out later, or reluctantly complete their programs rather than "waste" the investments of time, energy and money already made. More than fifty percent of freshmen intending to major in science, mathematics, or engineering fail to complete bachelor's degree programs in these fields, to say nothing of the many future teachers, communicators, managers, lawyers, political activists, public officials, and socially concerned citizens who are rendered permanently allergic to these fields by unfortunate experiences in introductory courses. Too many entry-level courses, whether geared to majors or to students satisfying general education requirements, fail to stimulate and involve students — much less educate them. Students complain that the courses are largely irrelevant to their lives and that the effort required far exceeds the benefit reaped.

In accord with these findings, the National Advisory Group identified the crisis as applying equally to entry-level courses for science, mathematics, and engineering majors and for students majoring in other fields.

Roots of the Crisis

In searching for the roots of the crisis in undergraduate education, members of the National Advisory Group hit repeatedly upon the theme of accessibility for students: access to instruction that generates enthusiasm and fosters long-term learning; access to a curriculum that is relevant, flexible and within their capabilities; access to a human environment that is intellectually stimulating and emotionally supportive; and access to a physical environment that supports the other three dimensions. These crucial components are strongly interrelated; weakness in any one diminishes the quality of undergraduate education.

Promoting these aspects of accessibility requires an appreciation of the intellectual readiness and psychological needs of the students — it calls for undergraduate educators to evolve approaches that enable and encourage students to progress from where they are to desirable levels of intellectual competence and maturation. College faculty may echo the sentiments of the Vermont farmer who advised the traveler: "If I wanted to get to where you're going, I wouldn't start from here." Yet, as much as adjusting entry-level courses to the students' level of knowledge may be contrary to the faculties' beliefs about what constitutes college-level work, to do otherwise is to abandon many potential majors as well as other students who take such courses for general education purposes to lifelong ignorance of the beauty and capabilities of science, mathematics and engineering. The necessity to adapt entry-level courses to the pre-college preparations of students is to recognize the fact that, in many cases, such preparation is deficient.

2 QUALITY OF INSTRUCTION

Topping the Advisory Group's list of factors essential for quality education in mathematics, science, and engineering at all levels is access to quality instruction. Professionals in these fields often report having become "hooked on" math or science through their experiences with an outstanding teacher. There is no simple recipe for generating quality instruction, but the National Advisory Group did identify its essential characteristics and some of its components.

Significance of Hands-on Experience in Investigation

Quality instruction requires of teachers, in addition to a thorough working knowledge of their fields, enthusiasm about working with students and the ability to share their knowledge and enthusiasm in ways that encourage their students to become full partners in the learning process. The Advisory Group agreed that the most effective way to engage students in active learning is to provide hands-on experience in investigations even in entry-level courses. Both classroom and laboratory work should emphasize the process of investigation rather than the exclusive memorization of facts and theories. To reiterate, effectiveness in both the classroom and the laboratory hinges on making the experiences relevant to students' lives and gearing them to the students' level (or, more accurately, just enough above the students' current level to make the work challenging but still accessible).

Good teachers are good listeners as well as good presenters. They listen carefully to students' questions and comments and allow the feedback to affect what and how they teach. They openly discuss problems concerning their courses and collaborate with students in trying to find solutions; they encourage communication and cooperation among students as well as between students and faculty.

Unquestionably, good teaching requires the expenditure of time and effort — to plan courses that satisfy well defined educational objectives, to prepare effective lectures and demonstrations, to develop and supervise meaningful laboratory experiences, to create examinations that test reasoning rather than memorization of facts, to read and respond to homework and examinations, and to enter into one-to-one discussions with students. It is well known that when it comes to tenure decisions, promotions and attendant salary increases, many colleges and universities penalize faculty who invest significant time and creative energy in undergraduate instruction. Star researchers advance rapidly; star teachers advance more slowly if at all, and may simply be denied tenure. Correspondingly, these institutions favor graduate programs in the allocation of resources, thus further undermining their often stated mission of "providing undergraduate instruction of the highest quality."

The Reward System for Excellence in Teaching

The National Advisory Group takes the position that it is essential for administrators -- both of academic institutions and of agencies and foundations that support research -- to address the consequences of current practices in rewarding research efforts and directly or indirectly penalizing faculty for their teaching efforts. Administrators must assess the direct effects of these practices on the willingness of faculty to devote time and effort to teaching and the indirect effects on both the quality of undergraduate education in science, mathematics and engineering and the number of students who major in these fields. Further, the Group recommends that effective, non-threatening faculty development opportunities be provided within colleges and universities to improve teaching skills.

Reliance upon Teaching Assistants

The reliance of many research-oriented universities on teaching assistants who lack the motivation, preparation, and (especially in the case of some foreign students) the communication skills to teach well strikes another blow at the quality of undergraduate instruction. Some departments and institutions are confronting this problem through programs that prepare teaching assistants to teach. Well prepared and trained assistants enhance rather than diminish the undergraduate experience. Students find one-to-one contact with capable and enthusiastic teaching assistants rewarding, although the National Advisory group does not believe that such contact can substitute for direct contact with experienced faculty members. Furthermore, the training invested in the assistants contributes to creating a cadre of future scientists, mathematicians, and engineers who can teach effectively.

3 QUALITY OF THE CURRICULUM

Quality of instruction centers on how students learn and the effectiveness of the learning enterprise. Quality of the curriculum is centered on the structure of student learning experiences — what students are exposed to and what students are allowed to explore. Members of the National Advisory Group have found that deep concern and sense of responsibility about the nature and quality of science, mathematics and engineering education permeate an increasing number of educational institutions at administrative and departmental levels, and all science, mathematics and engineering professional organizations. This profound concern represents a tremendous force for change and strong leadership is beginning to emerge from within departments and professional societies. Herein lies great promise, but also great risk.

Goals of Faculties vs Expectations of Students

Scientists, mathematicians and engineers who are strongly oriented toward cutting edge research press to move their best students as effectively and rapidly as possible into graduate study and sharply focused disciplinary research. Students, on the other hand, know only a multidisciplinary world and it is the science, mathematics and engineering in that multidisciplinary context that attracts them. Hence the student plea for relevancy, "To what am I being swept and why?"

In the previous discussion of the missions of science, mathematics and engineering undergraduate education, the various missions were listed (page 1) in decreasing order of the value commonly placed upon them by strongly discipline-oriented scientists, mathematicians and engineers. Students might order these missions quite differently — and would perhaps include other missions. That which the student finds in contemporary science education may not be consistent with that which the student seeks.

The Maturation of the Disciplines

In structuring curricula, attention must be given to the consequences of the maturation of the disciplines. Data bases, methodologies, concepts, theories and models have expanded tremendously. This quantitative expansion imposes the necessity to select. In addition, the levels of abstraction of concepts, theories and models have escalated continuously. These higher levels of intellectual demand on the student make it necessary for faculty to learn how to prepare and lead entry-level students to higher and higher levels of abstraction. We may now be asking students to assimilate abstractions before they have sufficient experience with the phenomena that are the rational base of the abstractions and, in so doing, we may be making science, mathematics and engineering inaccessible to many students.

Problems associated with the maturation of disciplines may be particularly acute for physics, chemistry and mathematics. These are among the most mature and the most abstract disciplines. These three disciplines are also elusive for quite another reason: physics and chemistry are applicable to all physical and biological systems and mathematics is applicable to all physical, biological and social systems. There is no system that is unique to any of these three. Consequently, counselors, students and parents often have difficulty identifying with physics, chemistry and mathematics: their relevance is pervasive but diffuse.

Entry-level Courses

Entry-level courses are not sufficiently rewarding to encourage and enable large numbers of students to pursue careers in science, mathematics and engineering. Entry-level courses are not sufficiently rewarding to encourage and enable students to embark 1) on life-long extensions of their knowledge and understanding of broad areas of science, mathematics and engineering at least at the level of the mass media, and 2) on life-long participation in the value judgments inherent in the resolution of societal issues involving science, mathematics, engineering and technology.

The National Advisory Group took the position that entry-level courses in major sequences and also entry-level courses in general education distribution sequences, including core course sequences, must be rethought from the perspectives of the students as well as the perspectives of the faculty. The National Advisory Group agreed that entry-level courses are the watersheds that will determine the future of science, mathematics and engineering education in this nation and thus will influence the capabilities of:

1) A public to make value judgments based on understand-

ing the nature and magnitude of the benefits and burdens inherent in technological change,

2) A work force to contribute to the vitality of technological enterprises and in so doing derive the benefits from employment in those enterprise, and

3) A cohort of scientists, mathematicians and engineers to initiate and sustain the research and development essential to the stability and growth of a technological nation.

The National Advisory Group agreed that first-rate faculty should be involved with entry-level courses and delineated many of the qualities essential to these courses. At the top of that list was attention to the processes of investigation, preferably via hands-on experience. It is through an understanding of processes of investigation that students discover: 1) that there are things scientists, mathematicians and engineers can do and other things they can not do, and 2) that experimental results are not exact but that scientists, mathematicians and engineers can usually evaluate the range of uncertainty within specified confidence limits (probabilities). The development of an understanding of the powers and limitations of science, mathematics and engineering is essential to rational participation in the resolution of societal issues.

Emphasize Thought Processes and Intellectual Skills

Minimize Memorization of Facts

A common student criticism of entry-level courses is that these courses are memory courses — pure memory. The National Advisory Group was adamant that entry-level courses should focus upon thinking, analysis, synthesis, critical reasoning and understanding and that the current emphasis on memorization of facts be minimized and, wherever possible, eliminated. In the opinion of some members of the National Advisory Group, the fallacy of focusing on transferring into the minds of students portions of the data base (followed by testing) may be the most important issue identified by the National Advisory Group. Facts alone do not an education make. Facts are soon forgotten and the experience is not a base for critical thinking. By the same token, the structure of nationally administered tests whose results influence the admission of students to graduate schools, professional schools and professional practice merits careful reevaluation to assure that such tests focus on the mastery of thought processes and intellectual skills, not primarily on recall of the data base.

Aesthetic and Human Dimensions of Science, Mathematics and Engineering

Value was also placed upon enabling students to discover the aesthetic and human dimensions of science, mathematics, engineering and technology. Such a discovery contributes immeasurably to an understanding and appreciation of the creativity of the human mind and what it means to be human. This has much more to do with the context within which topics are presented than it has to do with the structures of curricula.

Development of Entry-level Courses for the General Student

As a nation we have very little experience in developing entry-level courses to serve the unique needs of general students who do not choose to elect the entry-level courses for majors in science, mathematics and engineering. There are two options: 1) develop within departments entry-level courses that are cast in an interdisciplinary context, and 2) develop in cooperation with other departments an interdisciplinary sequence. A six-quarter sequence, developed around the concept of physical, chemical and biological evolution was suggested at the Wingspread meeting (See Appendix Three).

Upper-level Courses for the General Student

Ideally, there should also be one or more upper-level courses for general students. For example, a course based upon case studies of selected societal issues could be exciting and the basis for integrating the social sciences, the physical sciences, biological sciences, mathematics, engineering and technology with each other and with the humanities. Through case studies students have the opportunity to discover that the roles of scientists, mathematicians and engineers (as scientists, mathematicians and engineers) are to identify issues, develop deeper understandings of issues, assess the magnitude of issues, identify or develop technological options to resolve or ameliorate societal issues, assess the probable benefits and burdens associated with each option, and articulate these assessments in such a way that professional communicators can present these assessments clearly and faithfully to the public. It is the public (including of course, many scientists, mathematicians and engineers) or its surrogates that make the decisions (the value judgments) about the implementation of an option.

The Support Systems Required for the Development of New Courses

To develop new courses and sequences requires the support of the institution and the departments involved, as well as the talents, enthusiasms and commitment of dedicated members of the faculty. Outside funding may also be essential for the development of imaginative, fine tuned, entry-level courses.

The Major

Entry-level Courses

The diversity of students entering major sequences is so great that departments may find it expedient to offer more than one entry-level course. If so, each course should still incorporate the characteristics delineated for entry-level courses for the students not planning to major in science, mathematics and engineering. This is particularly true for honors courses and advanced placement courses. The fact that these students can cope with the technicalities and abstractions of a more advanced course in a discipline, does not mean that they understand the interdependent nature of the sciences, mathematics and engineering and the significance of the discipline to societal issues. Too much too soon about too little may contribute to the fade out of these students. They simply do not know where the track leads.

Major Sequences

The National Advisory group did not address the details of course structures and the sequence of courses in the major. These matters are highly discipline specific and best addressed by the members of the departments involved and the relevant professional societies. However, the National Advisory Group points out that students are intimidated and inhibited by majors that are too tightly sequenced. Students are inclined to see a tightly sequenced major in a discipline as a one-way road to be entered in the freshman year and exited, without penalty, only at the completion of the major in the senior year.

Traditionally Under-represented Groups

Women, minorities and the physically disabled may be particularly apprehensive about their abilities to stay the course and consequently, may be inhibited in electing majors in science, mathematics and engineering. There are few role models to give them confidence. The departmental structure of academic institutions, limited communication between departments, and the departmental possessiveness for their students are not conducive to the discovery by students that science, mathematics and engineering really are interdependent in nature. Undergraduate curricula should be viewed as a network of roads with many points of entry, and many crossovers — points of opportunity to broaden academic programs and move to other majors. Students need the security of knowing that with unusual but relevant backgrounds they can enter majors somewhere along the way, that majors midstream can frequently enter upper-level courses in other departments with backgrounds other than the stated prerequisites, and that majors in one department can transfer to majors in other departments without penalty. Students need help in discovering that experience and academic maturity are negotiable currencies. All of this is part of the human environment so important to students.

Accessibility and Flexibility of Curricula Essential to Student Mobility

A narrow focus on a single discipline as an undergraduate may be related to the reluctance of many graduates to take technical positions outside their undergraduate major discipline. If this is true, the National Advisory Group's fifth topic, "accessibility and flexibility of curricula essential for student mobility" has much more significance than might be apparent on first reading. Students underestimate how learning to define problems, to think critically, to analyze and to synthesize prepares them to explore widely throughout their professional lives and to be creative and productive citizens regardless of the precise nature of the career. Data bases can be acquired as needed. Informed counseling is essential, but it is the understanding of the interdependent nature of the sciences, mathematics and engineering that is important. Building this understanding should begin in entry-level courses and continue throughout the undergraduate years.

Interdisciplinary Majors

The breadth of an interdisciplinary major and the phenomena investigated are frequently attractive to students. However, many scientists, mathematicians and engineers question whether the sacrifice of depth in obtaining breadth is too high a price to pay. One test is to determine whether the depth is sufficient for the student to be admitted and proceed directly with graduate study. If not, the lack of depth may also restrict employment opportunities at the BS level. Another approach to breadth is for the student to take a carefully structured limited major supplemented by carefully chosen upper level courses in departments of the student's interest. In recent years we have been finding that many upperclass students, with some guidance, can negotiate many upper-level courses without the stated prerequisites. There is nothing better than for students to take the responsibility for their education and administrators and faculties should encourage and facilitate their endeavors to do so.

The Undergraduate Laboratory Experience and Research Experience

The National Advisory Group considers the undergraduate laboratory experience and research experience to be the most valuable parts of any major in science, mathematics and engineering and the National Advisory Group urges that every effort be made 1) to develop laboratories, beginning with entry-level courses, that provide experience with process, and 2) to incorporate research in the undergraduate experience of every major in science, mathematics and engineering. Research experiences may be within the department, in other departments, in other academic institutions, in industry and in other types of laboratories — any place and any time the student has the opportunity to work in an adequate laboratory with a competent scientist, mathematician or engineer.

Education for Leadership

The participants in the meeting were committed to the concept that BS graduates must be prepared to be more than just scientists, mathematicians or engineers. They should be prepared to become leaders overall, not just within their professions. To that end, the National Advisory Group recommends that departments and individual faculty members assist their major students to:

- Plan and pursue coherent programs of studies in the humanities, and
- Acquire both oral and written communication skills.

It is not enough to specify credit hours in humanities and communications. Such specifications become requirements to be checked off, frequently without conviction that there is value in the process. Under such circumstances, students may select courses on the basis of convenience in scheduling and reputation for requiring minimal outside work. A sense of conviction can be derived by students from the faculty with whom they work. Enthusiasm for the pursuit of the humanities can be fostered through explorations with faculty members of how to select work in the humanities best suited to the extension of personal interests and discovery of areas of their cultural heritage unknown to them. Communication skills can be acquired effectively through the course work of the major department — where there is compelling need to communicate.

Structural and institutional barriers to curriculum change are explored briefly in the last section of this report (pages 21 - 22).

4

QUALITY OF THE HUMAN ENVIRONMENT

Significance of the Human Environment

Throughout the explorations of the National Advisory Group, quality of the educational environment was always a part of the discussions but it was not until the last session of the Group that the quality of the human environment emerged as a significant topic in itself and it was ranked third (page iv) in the final list of seven topics that policy makers should address in formulating policy for undergraduate education in science, mathematics and engineering. Only the quality of instruction and the quality of the curriculum were ranked as more significant.

Roles of the Faculty in Determining the Academic Environment

The quality of the human environment is determined by the nature of the interactions among students, faculty and administrative personnel. In keeping with the mission of undergraduate education to encourage and enable students to achieve personal and professional goals, and the dominant role (as perceived by the students) of the faculty, this discussion focuses upon the roles of the faculty, individually and collectively, in enhancing the quality of the human environment for students. This is, of course, a limited aspect of the larger topic.

What an individual faculty member does or does not do may be a reflection of the values and sensitivities of that individual but it also may be a reflection of long standing academic practices unquestioned by the individual faculty member. Practices that negate the mission to encourage and enable can be pernicious and should be eradicated. Three examples:

1) Statements to students such as "Look to the left of you, look to the right of you. Only one of you will complete the program;"

2) Harsh testing and grading practices with grade averages well below prevailing institutional grade averages; and

3) Statements to students such as "You are too good to go into secondary school teaching."

Established practices that arose originally from elitism and discrimination were of particular concern to the National Advisory Group.

Ideally, faculty value diversity in the composition of both the student body and the faculty and in the characteristics of the academic programs pursued by students. All students are welcomed equally regardless of ability, age, sex, race, intended major or quality of previous preparation. Each student is valued as an individual and accorded the same support and esteem as all other students. There are no second class citizens. Each is supported in his or her choice of major, development of academic program and pursuit of professional goals.

Ideally, faculty work to lower the barriers dividing scientists, mathematicians and engineers into three communities. To do so (now that the symbioses among the three fields of endeavor become increasingly apparent with current developments in the overlap between fields) is increasingly feasible and important in enhancing the quality of the human environment of students and faculty alike.

Roles of the Faculty as Mentors and Role Models

The preceding discussion has been in terms of academic routes through which faculty enhance the quality of the human environment. The following discussions focus on the role of faculty as mentors to students making adjustments to cultural changes as they become a part of the academic community and, in many cases, as they seek to become a part of the culture of adult scientists, mathematicians and engineers.

Ideally, faculty empathize with the psychological issues that occupy many of their students: struggles over separation from parents, choices of occupation, culture shock in moving from high school or job or military service into a college program. Faculty participate in one-to-one contacts that allow students to use them as mentors or models in their struggle to find their place and prosper in the new culture. In the case of four-year undergraduate campuses, faculty are sensitive to the particular hopes and fears of students transferring from two-year colleges. These transfer students are pleased to have gained admission to the four-year program, but fear that they may falter under the (perceived) greater demands of their new environment. Faculty address these specific concerns by supportively joining the students in assessing the adequacy of their preparation, taking care to validate its merits, and providing suitable opportunities for filling in gaps as required. Similarly individualized attention and support are needed for students who have begun their education in science, mathematics or engineering in non-traditional settings such as the armed forces, proprietary schools, in-house industry training programs, and technical institutes.

Students from groups that are typically underrepresented in science, mathematics and engineering frequently need help in combating destructive legacies of long-term discrimination (and in some cases inadequate preparation). Many have been indoctrinated with defeatist attitudes regarding their capabilities to do mathematics, science and engineering. Ideally, faculty work to add members of underrepresented groups to their faculties and bring professionals from these groups as role models to campus for as much contact with students as possible. However, all faculty, regardless of race or sex, can and should serve as mentors to these students. Perhaps most important is the repeated reinforcement of the message to these students that they are pioneers who, by forging professional identities that fit their unique cultural heritages, will become models for increasing numbers from their group who follow them. A number of colleges and universities have created supportive environments for special groups and some have achieved excellent retention rates.

The National Advisory Group agreed that faculty are particularly effective as mentors and role models. Many professional scientists, mathematicians and engineers cite the support of a faculty member or, in some cases, a teaching assistant, as instrumental in their continuation in science, mathematics or engineering. There are, however, two very practical questions that must be addressed within each institution: How much effort can faculty members (within the current cultures of their own institutions and departments) afford to devote to mentoring? and To what degree can administrative personnel fulfill the mentoring roles for students?

5 QUALITY OF THE PHYSICAL ENVIRONMENT

The National Advisory Group expressed concern that college and university administrators, under the pressures of financial constraints, were eliminating the laboratory experience for students — particularly for students in entry level courses. The Group considered this retrenchment antithetical to the frequently stated goal of many colleges and universities of "providing undergraduate instruction of the highest quality." With full appreciation of the inadequacies of laboratory space, laboratory facilities, instrumentation, computer facilities and library holdings, the National Advisory Group focused on educationally appropriate use of equipment and educational technology rather than the delineation of appropriate inventory and acquisition.

Deficiencies in the Laboratory Experience

There are problems with the undergraduate laboratory experience. Many students recognize that laboratory work frequently consists of exercises, not experiments, and that grades can be based upon getting "the right numerical value" for a quantity rather than analyzing the uncertainties inherent in the methodology and the instrumentation. This is particularly troublesome to them when they suspect that the prescribed methodology and the available instrumentation are incapable of giving "the right numerical value." To them there are two choices: be honest and get a poor grade or be dishonest and get a good grade. They also recognize that, in some courses, the grading system encourages them to draw broader conclusions than their experimental results justify. The concept of the integrity of data can be compromised before they start.

Laboratory work that merely trains students in the execution of well-defined methodologies has very little long-term educational value unless those methodologies are used in some meaningful way to carry out an investigation. Laboratory work can provide significant experience with the process of investigation and this is the type of experience that must be made available to students.

Emphasize the Process of Investigation

Use of Educational Technology

The National Advisory Group took the position that educational technology should be used to enhance instruction but can not replace the instructor. Computers represent the most significant new educational technology. Two examples of the constructive use of computer simulations are: 1) to provide students with mock experiences with complex equipment preceding hands-on experiences with that equipment in the laboratory in order to dissipate student anxiety, save time and protect the equipment, and 2) to display graphically changes in numerical values as predicted by a specific model, in response to variations of the parameters in the model. The first example is reassuring to students. The second example can be spectacularly effective in elucidating complex concepts. The National Advisory Group supports appropriate uses of computer simulations but takes a very strong position against their use to replace laboratory hands-on experience. Students need to learn to critically assess computer simulations, to question the models on which they are based, and to recognize that simulations are not true science or engineering investigations. To understand the powers and limitations of computer simulations is an important part of computer literacy.

The National Advisory Group recommends that educational technology be carefully investigated to determine its quality and effectiveness in undergraduate education in science, mathematics and engineering.

6 FULFILLING THE MISSIONS

The curricular needs of technically oriented majors and the needs of general students have been discussed in some detail in 3, Quality of the Curriculum (page 8).

Needs of School Teachers, Communicators, Lawyers and Managers

The National Advisory Group also addressed the curricular needs of undergraduate students who expect to become school (K-12) teachers, communicators (journalists), lawyers and managers. Among the Wingspread participants were individuals from these professions or from professional schools which prepare students for these professions. In all cases, the conclusions were the same. The current undergraduate curricula in science, mathematics and engineering in most academic institutions are not sufficiently accessible, flexible and relevant to meet the professional needs and interests of such students but the kind of curricula proposed in this report move in the right direction.

Elementary school teachers journalists, lawyers and managers need the experience characteristic of the program designed for general education in science, mathematics and engineering. They need to develop an understanding of process, to have hands-on experience with process including laboratories and computers, to discover both the powers and the limitations of science, mathematics and engineering, to have some level of experience with the unification of facts through concepts, models and theories, and a familiarity with the nature of the data bases of science, mathematics and engineering. They also need some understanding of the relation of science, mathematics, engineering and technology to the quality of life; the roles of scientists, mathematicians and engineers in the resolution of societal issues; and the role of the public (including scientists, mathematicians and engineers) in the resolution of societal issues.

Prospective elementary school teachers, communicators, lawyers and managers can, of course, elect major sequence courses — even majors — whenever this more intensive experience with science, mathematics and engineering is consistent with their interests or professional plans.

Prospective middle and secondary school teachers of science and mathematics can meet their curricular needs through the combination of a carefully planned minimum major and carefully selected courses from major sequences and general education sequences in other departments to build strength and breadth in other fields. The National Advisory Group felt strongly that the major for middle and secondary school teachers should be in the intended teaching field, rather than in education. Potential middle and secondary school teachers need to develop the critical analysis and thought process skills expected of all majors in science, mathematics and engineering. Those preparing to teach at the middle school level need, in addition, special knowledge of the psychology of early adolescence.

The message was very clear. If academic institutions develop appropriate major sequences and general education sequences in science, mathematics and engineering, these two sequences, along with informed counseling, will enable potential school teachers, journalists, lawyers and engineers to pursue their career goals.

The Great Significance of the Symbiotic Nature of Science, Mathematics and Engineering

The great potential of science, mathematics and engineering to contribute to the well being, economic development and international competitiveness of the nation lies in the symbiotic nature of science, mathematics and engineering. Great advances in knowledge and in technology do not usually occur today in science or in mathematics or in engineering but in the total realm of science, mathematics and engineering. In NSF, where the word "science" is used to encompass mathematical science, the title NSF Directorate for Science and Engineering Education is a step towards basing education on the symbiotic nature of science, mathematics and engineering, and enabling students to become creative participants in the expansion and use of knowledge in the context of that symbiosis.

These matters were touched on at the Wingspread meeting but not explored by the entire group. Barriers that operate against dynamic curricula in stride with the evolution of our understanding of this symbiosis deserve in-depth exploration by a diverse group such as the Sigma Xi National Advisory Group. These barriers include the departmental structure of academic institutions, the accreditation system for engineering programs and the focused nature of institutional funding. Departmental structure emphasizes differences, accreditation imposes the concept of static bodies of knowledge on science and mathematics, and the funding of science separate from engineering nurtures the introspective nature of science.

Grounds for Optimism

The participants at the Wingspread meeting were optimistic and committed. Significant topics are easily identifiable. Some of the right questions are being asked. There is a ground-swell of concern throughout the nation in professional societies, in the research community, in industries, in foundations, in governments and government agencies, as well as among faculties and administrators of academic institutions.

Enormity of the Needs

The participants were challenged by the enormity of the needs and how much we must learn. We know that the non-competitive reward system for excellence in undergraduate teaching severely limits innovation and the quality of teaching, but we know very little about how to bring about change in the attitudes, perceptions and practices of those who contribute to this reward system. We know that entry-level courses must be rethought, archaic materials eliminated, contemporary materials incorporated, and the courses made more relevant to students, but those who teach know so little about how students learn at the college level and how their capacities to cope with the abstractions of modern science, mathematics and engineering develop.

We talk about the relation of science, mathematics and engineering to societal issues but many of those who teach have thought little about these matters. We recommend the use of case studies but few teachers can easily identify cases for which detailed information is readily available. We know that some minorities, women and others need support, that faculty are essential in the provision of that support, and that there may be a great deal to learn from the smaller liberal arts colleges in this regard. But very little is generally known about what types of support are needed in large institutions, what others have tried, what has succeeded and what has failed. We know that interesting things are going on in the development of entry-level courses but there is no efficient way to identify where these developments are in progress or to transfer these experiences to other institutions. The list could go on.

Diversity of Participants

The fulfillment of the missions of undergraduate education in science, mathematics and engineering requires the participation and leadership of many communities, organizations and institutions. Some of that participation and leadership is arising within foundations and industries, governments and government agencies, and the community of scientists, mathematicians and engineers (including the professional societies) as well as within the colleges and universities.

Not all of this leadership leads in the same direction. For example, the leadership of a single-discipline professional society in developing a tightly sequenced curriculum in preparation for graduate study or professional employment at the BS level in that discipline may run counter to the leadership of academic administrators building for flexibility within the total curriculum of the sciences, mathematics and engineering departments.

Resolving some issues requires the cooperation of many players. For example, resolving the non-competitive reward system issue requires the participation of college/university administrators and department members, government officials, members of the research community and, in particular, the directors of research granting agencies and foundations. The value system that determines the psychological and monetary reward systems arises from the perceptions, attitudes, values and practices of these players.

Initiatives Appropriate to Congress and the National Science Foundation

The National Science Foundation under its mandate from Congress as the lead federal agency for science, mathematics and engineering education has unique opportunities and responsibilities to provide national leadership. The Sigma Xi National Advisory Group on undergraduate education in science, mathematics and engineering strongly urges the Congress and the NSF Directorate for Science and Engineering Education to implement eight initiatives judged to be key to the direct enhancement of undergraduate education in science, mathematics and engineering, and through that the indirect enhancement of education at all levels including adult education. These initiatives were listed in Findings in Brief (page vii) and are repeated here:

> Open and forthright discussion and evaluation of the factors that make the reward system for excellence in

undergraduate teaching non-competitive with the reward systens for excellence in other professional activities of scientists, mathematicians and engineers;

- Scholarly research related to learning at the undergraduate level;
- Development of more appropriate entry-level undergraduate courses for 1) majors and 2) general students in science, mathematics and engineering;
- Enhancement of the quality, breadth and contemporary nature of upper-level courses in science, mathematics and engineering;
- Development of process-oriented laboratories for all students at all levels in science, mathematics and engineering;
- Participation of majors in science, mathematics and engineering in student research;
- Entry and sustained professional development of women, underrepresented minorities and physically disabled in science, mathematics and engineering; and
- Exchange of information among those developing innovative undergraduate curricula — particularly entry-level courses.

APPENDIX ONE: THE WINGSPREAD MEETING

Sigma Xi, The Scientific Research Society with the support of the National Science Foundation and The Johnson Foundation invited a National Advisory Group of thirty-five to meet at Wingspread in Racine, Wisconsin, January 23-26, 1989, to explore the nature and quality of undergraduate education in science, mathematics and engineering. The charge was to identify the significant topics and issues that policy makers should address in establishing policies for undergraduate education in science, mathematics and engineering. The total group, including Sigma Xi officers, observers and Wingspread Fellows participating in the exploration, was forty-four.

Three formal presentations provided the background for the exploration by addressing the missions of undergraduate education in science, mathematics and engineering as perceived by entering freshmen, by academic administrators and by the public:

Keynote Address: **A Profile of Undergraduates in the Sciences,** Kenneth C. Green, Higher Education Research Institute, University of California, Los Angeles (Appenix Four)

Missions of Undergraduate Education in Science, Mathematics and Engineering as Perceived by Faculties and Administrations, Fredrich H. Shair, Department of Chemical Engineering, California Institute of Technology

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APPENDIX THREE: A SIX-QUARTER ENTRY-LEVEL SEQUENCE BASED ON THE CONCEPT OF EVOLUTION

This sequence of course is currently taken by about twenty percent of the undergraduates at the University of Chicago and is well received by the students who elect it. The titles of the six quarters are given as an example of an imaginative interdisciplinary sequence. The delineation of this sequence here in no way implies that it could or should be transported to another institution or that it should or will be institutionalized at the University of Chicago. Many other interdisciplinary sequences could be derived around other themes by enthusiastic faculty members coming together from different departments. It may be that the natural thing is for sequences of this type to come and go as the faculty of an institution change.

Nat. Sci. 101	Evolution of the Universe: Big Bang to Star Formation
Nat. Sci. 102	Evolution of the Solar System and the Earth
Nat. Sci. 103	Evolution: Chemical to Biochemical
Nat. Sci. 104	Biological Evolution
Nat. Sci. 105	Design and Function of Organisms
Nat. Sci. 106	Organism to Ecosystems

For further information about this sequence contact Michael La Barbera.

APPENDIX FOUR: THE KEYNOTE ADDRESS A PROFILE OF UNDERGRADUATES IN THE SCIENCES[1]

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The health and vitality of the "pipeline" of students planning undergraduate work in the sciences is an important indicator of the human resource component of the nation's science resources. For more than two decades early indicators of undergraduate interest in the sciences have been tracked by the annual American Council on Education — UCLA Cooperative Institutional Research Program (CIRP) survey of entering college freshmen. Begun in 1966, the CIRP is now the nation's largest and oldest empirical study of higher education. The annual CIRP freshman and follow-up surveys are a rich resource for data about the students who pursue higher education in the United States. In recent years more than 300,000 students attending some 600 two- and four-year colleges and universities across the country have participated in the annual CIRP survey of college freshmen.

The CIRP staff have been able to "cut" the freshman survey data to develop normative profiles of students by ethnicity, by ability level, and by intended college major. Drawing on cross-sectional and longitudinal data, the CIRP offers a unique resource for studying the undergraduate pipeline in the sciences.

This paper focuses on the population of freshmen who enter college planning to pursue a science major. It offers a comparative profile of science-oriented students against students planning other majors; it also compares the profile of science students within various science fields. This work draws on data from 1988 CIRP Freshman Survey, from previous CIRP surveys of entering students, and from a 1986 follow-up study of 1982 and 1984 college freshmen.[2]

Some Initial Findings — and Conclusions

The CIRP data point to a simple and direct conclusion. *We must recognize that the infrastructure of the American educational pipeline in the sciences and resulting human resource capacity in the sciences and technology has suffered serious erosion over the past two decades.* The evidence from the CIRP surveys is very persuasive:

- Freshman interest in fundamental undergraduate science majors has dropped dramatically — by almost half — over the past 23 years.
- Freshman interest in technology careers has experienced a dramatic decline in just the past six years. Between 1982 and 1988, the proportion of freshmen planning to pursue careers as engineers fell by almost one-quarter; the proportion of freshman planning to pursue careers as computer professionals has plummeted, falling by nearly three-fourths in just six years.
- Every year tens of thousands of academically-able students enter college planning to pursue

science majors. Yet more than half of these students change their intended major for other, non-science fields. Moreover, the high "defection" rates for aspiring science majors are not offset by recruits from other (non-science) fields.

- The disciplinary-training of secondary school science teachers has declined dramatically over the past two decades. Today very few aspiring science and math majors plan to pursue careers as high school teachers.
- Finally, if undergraduate science departments were run like for-profit businesses — that is, without substantial institutional subsidy — most programs might be bankrupt, largely because of their capacity (some might say basic inclination) to "alienate" potential clients.

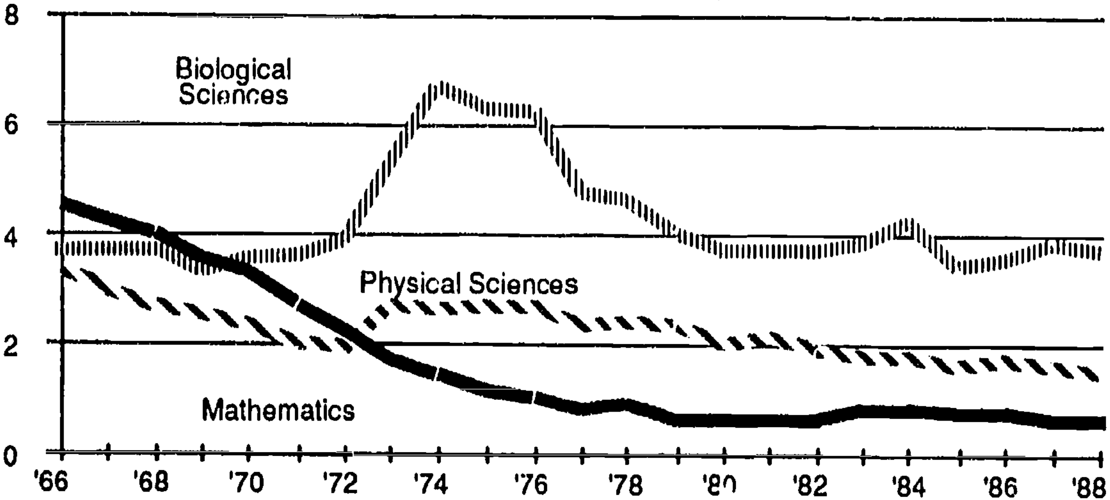
There is, of course, the risk of sounding like an alarmist or echoing the increasingly common refrain of a series of recent national reports bemoaning the increasing scientific illiteracy of Americans and the declining scientific performance of American students in international comparisons. However, the declines in science capacity reflected in the CIRP data (and in other sources) point to serious problems for the science-based infrastructure of the nation's labor market and the country's capacity to respond to the scientific, technological, and economic challenges of the 1990s and the next century.

General Trends In Freshman Interest In the Sciences

Between 1966 and 1988, the proportion of college freshmen3 planning to major in the biological sciences, the physical sciences, and mathematics fell by half, from 11.5 to 5.8 percent (Figure 1). The largest portion of this decline occurred in mathematics: over the past 23 years the proportion of aspiring mathematics majors dropped from 4.6 to 0.6 percent, a decline of more than four-fifths. In the physical sciences (i.e., chemistry, physics and related fields), freshman interest has fallen by more than half, from 3.3 percent in 1966 to 1.5 percent in 1988. Only the biological sciences have maintained a stable "market share" of freshman interest: in Fall 1988, 3.7 percent of the entering freshmen planned to pursue majors in biological science fields, about the same as the recorded in the late 1960s, but well below the peak numbers recorded in the mid-1970s (when more than 6 percent of the entering freshmen expressed interest in bioscience majors).4 However, the seemingly stable interest in the life sciences primarily reflects stable career aspirations for medical careers rather than any intrinsic interest in biological science majors. Many of the aspiring bioscience majors

Figure 1: Freshman Interest In Science Majors

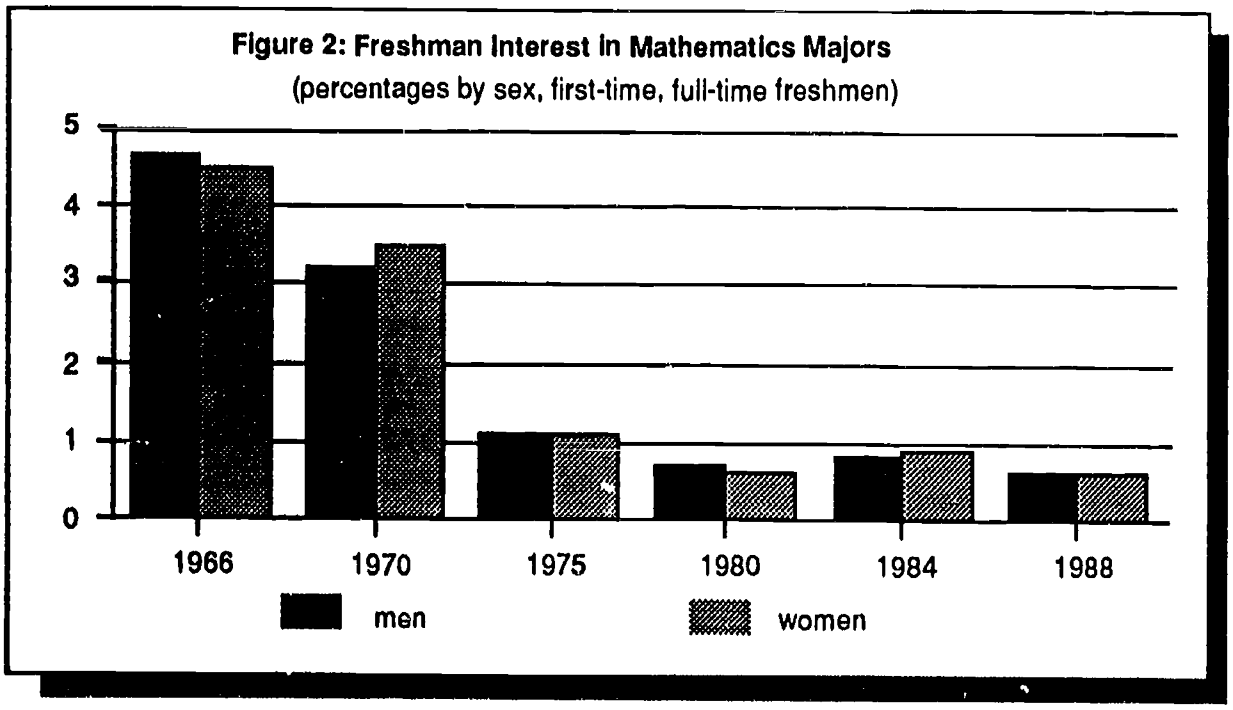
(percentages, 1966-1988)



who really harbor aspirations for medical school will ultimately change their majors and career preferences when they confront organic chemistry, a traditional "point of departure" for many pre-med students.

The trends by sex for science majors paint an interesting — and in many way surprising — portrait of the past two decades. The conventional wisdom might suggest that interest in basic science majors among freshman women should have *increased* over the past two decades, as women presumably received more encouragement to pursue "non-traditional" majors and careers However, the CIRP data suggest that women's interest in science majors *dropped* by more than two-fifths during this period (from 8.8 percent in 1966 to 5.1 percent in 1988). Admittedly, this decline among women is far less than the nearly one-half decline in these same fields posted among men (from 13.8 percent to 7.0 percent) during the same period). However it does run against the conventional wisdom and should be particularly distressing given the range of government, institutional, corporate, and philanthropic efforts to encourage young women to pursue training and careers in the sciences.

The high losses in freshman interest in mathematics majors play a strategic role in the larger issue of science capacity. For example, there is the dramatic drop in freshman interest in mathematics majors (down by more than four-fifths over the past 23 years). This decline occurs among both men and women (Figure 2). It should concern us for several reasons.



First, there is the career path of math majors. Two decades ago the women who earned undergraduate math degrees often took teaching jobs in secondary schools. These women played a pivotal role in secondary mathematics education. First, they represented a large (if unfortunately all-too-often transient) part of the teaching pool in mathematics.

Second, although we did not refer to them in this context twenty years ago, these women math teachers served as important role models for adolescent girls who might be all too willing to forego the sciences despite their talents. However, as women's career aspirations and options expanded beginning in the late 1960s, we see that their interests moved away from mathematics and out of teaching. The disappearance of this pool of potential math teachers has been an important factor in the deterioration of the science-oriented education infrastructure: one significant if often undiscussed consequence has been the impact on secondary math and science instruction and the science pipeline coming out of our secondary schools and into college.

Technology Majors and Careers

The CIRP data also reflect student perceptions about the job opportunities for engineers and computer specialists (Figure 3). Freshman interest in engineering careers and majors fell precipitously during the early 1970s. This was the period just after the first Apollo moon walk *and* the termination of funding for the Supersonic Transport (SST) project and other large government contracts. Potential engineering students received ample doses of the televised images of unemployed engineers in Seattle, Long Beach, and St. Louis. Consequently, they opted for other majors. The rising interest in engineering careers that began after 1975 reflected both the *return* of men as well as the *rising* (if still small) number of women coming into engineering. Freshman interest in this area was further stimulated by the upheavals elsewhere in the economy: science/technology fields were the only "hot spots" in an otherwise down economy between 1977 and 1983. Over the past six years however, we have seen a surprising decline in freshman interest in engineering careers, from 12.0 percent in 1982 to 8.6 percent in 1988.

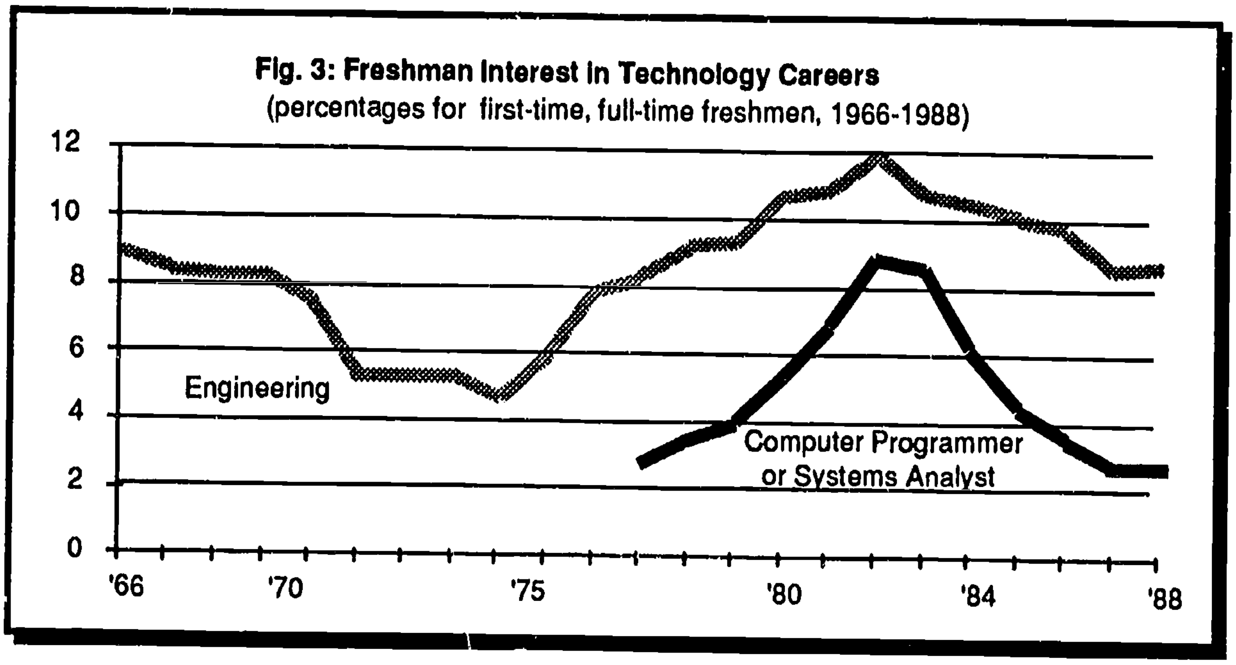


Fig. 3: Freshman Interest in Technology Careers
(percentages for first-time, full-time freshmen, 1966-1988)

The CIRP data show even more significant declines in the proportion of freshmen planning to pursue majors and careers in computing (i.e., as programmers or systems analysts). After rising posting almost geometric gains between 1977 and 1982, from 2.8 to 8.8 percent, freshman interest in computing careers has plummeted, falling back to 2.7 percent in 1988. This decline reflects the fastest and perhaps most significant drop in a career choice documented over the past 23 years in the CIRP data.

Like the concurrent decline in engineering, the decline in computing runs against the conventional wisdom about the job market and the job prospects for students with technical training. Why? Part of the explanation rests with what has happened in the labor market over the past decade. The only bright spot in the economy during the last recession and even during the high inflation that preceded it seemed to be technology areas. Yet the nation is now in the midst of a major transition in the structure of the economy; it is a transition that marks the movement away from manufacturing to service industries, to technology, and towards information systems. These areas became very attractive to many young people.

The late 1970s and early 1980s were also the period when Apple Computer came out of the garage and went onto the Fortune 500 and schools introduced a "bits, bytes and BASIC" approach to computer instruction.

Our analyses of the declining interest in technology careers in the recent years suggests that the drop is largely due to the "outmigration" or "defection" of the "B" students to non-science fields, rather than an absolute loss of the academically-able (i.e., "A") students who are intrinsically interested in science. In other words, the dire state of the economy in the early part of the decade prompted many science-capable "B" students to consider technical careers. As employment options improved in other sectors, many of the "B" students who could handle the science and mathematics requirements of the engineering and computer science curriculum moved into other fields.

Yet the recent decline in computer science majors also seems to be a consequence of increasing familiarity with the technology. As the computer literacy movement grew in the 1980s, more students had contact with computers. Moreover, the focus of activity shifted from programming to applications (e.g., word processing, spreadsheets, graphics). [The CIRP surveys indicate that over one-fourth (27.4 percent) of the 1988 freshmen "frequently used a personal computer" the year prior to entering college and nearly three in five (58.1 percent) had at least a half-year of computer instruction while in high school.] Consequently, as more students have exposure to computers, they (like many adults) now come to view the technology as a means to an end, rather than an end in and of itself.

In sum, the decline in freshman interest in science and technology fields has been both severe and significant. The CIRP data, which correlated highly with the trends in earned undergraduate degrees in these fields, point to a troubling deterioration in the science-oriented portion of our education and human-resource pipeline.

Trends in Other Majors and Careers

Where have the students gone if they are no longer interested in the sciences? Clearly it has been a bull market in business, particularly when we look at the shifts in career preferences by sex. Between 1972 and 1988, the proportion of freshmen planning to pursue business careers more than doubled, from 10.5 to 23.6 percent (Figure 4). And although business has declined slightly in recent years (from a peak of 24.6 percent in 1987), it is still the most popular career preference (and intended major) of today's freshmen, accounting for about one-fourth of the all freshman and about the same proportion of undergraduate degree awards (National Center for Education Statistics, 1987, p. 105.).

Fig. 4: Freshman Interest in Business Careers
(percentages, 1966-1988)

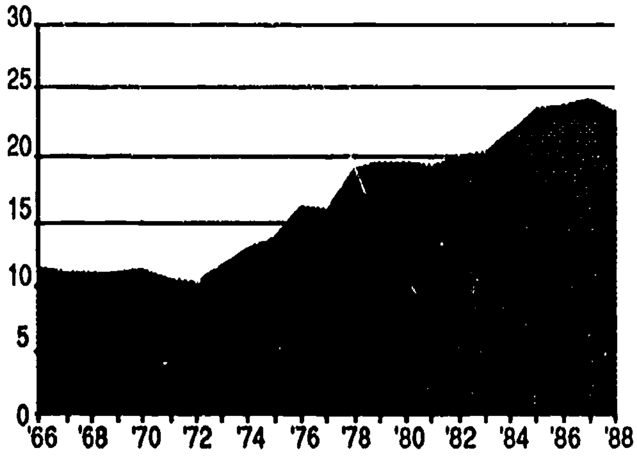
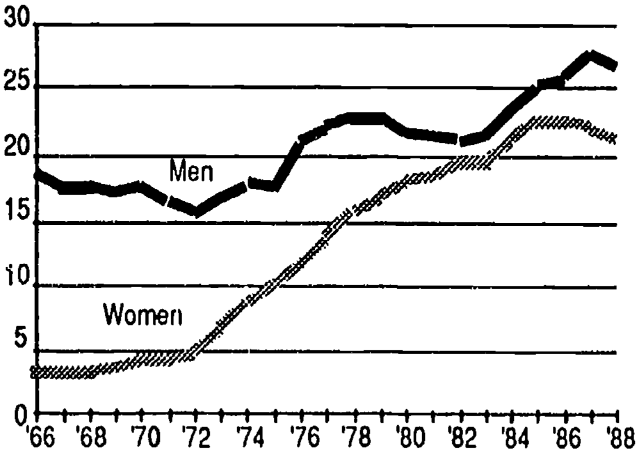


Fig. 5: Interest in Business Careers, By Sex
(percentages, 1966-1988)



Yet the overall shift in business masks the particularly dramatic changes that have occurred among women in the past two decades (Figure 5). Between 1966 and 1988, the proportion of freshman women planning to pursue business careers exploded, rising by a factor of more than 6 (from 3.3 percent in 1966 to 21.3 percent in 1988). Indeed, in some business specializations women now outnumber men. For example, for the past several years more freshman women than men have indicated their preference for accounting majors and careers.

The rising popularity of business seems to reflect students' efforts to prepare themselves for the job market they envision in the 1990s and on into the next century. Freshman interest in business remains high, despite the rising chorus of corporate leaders who say they want their organizations to hire well-read, well-trained people prepared in the liberal arts. That students *do not* accept this message seems to be their way of saying they know CEO's do not work the campus recruitment circuit. Moreover, the irony here is that students do not recognize the role of science as a resource for business careers. For example, undergraduate business majors will not be effective representatives for pharmaceutical companies; rather, to work in pharmaceutical sales and marketing students will need a strong background in the biological sciences and chemistry, along with strong writing, presentation, and interpersonal skills.

The pipeline in elementary and secondary school careers has also changed significantly since the 1960s. There is little question that these changes have had dire consequences for the sciences. Freshman interest in teaching careers fell from a peak of 23.5 percent in 1968 to a low of 4.7 percent in 1982 (Figure 6). Freshman interest in teaching has been rising recently, almost doubling to 8.8 percent in 1988; however, the current levels are still far below those recorded in the mid- and late-1960s, and well below the levels need to meet future needs (see, for example, Carnegie Forum, 1986; National Commission on Excellence in Teacher Education, 1985). Moreover, even with the recent gains in student interest in teaching careers, the CIRP data reflect comparatively little interest in secondary school assignments. This should be particularly distressing for science educators as junior high school and secondary school science and mathematics courses stimulate student interest in these fields and provide the academic foundation for subsequent undergraduate work in these areas.

Also distressing is the loss of the population of "discipline-trained" teachers. Twenty years ago a significant proportion of aspiring teachers planned to pursue majors in liberal arts fields, including the sciences. At present however, the CIRP data suggest that virtually all the freshmen planning to pursue teaching careers now plan to major in education rather than in other, more "academic" disciplines (Figure 7). The concern here, of course, is that future teachers — in English and literature, in the sciences and social sciences — may not have an adequate disciplinary base for the demands of the secondary school curriculum. The teaching profession is now wresting with various proposals to enhance the disciplinary requirements for teaching certification (e.g., enhancing minimum certification requirements so that all

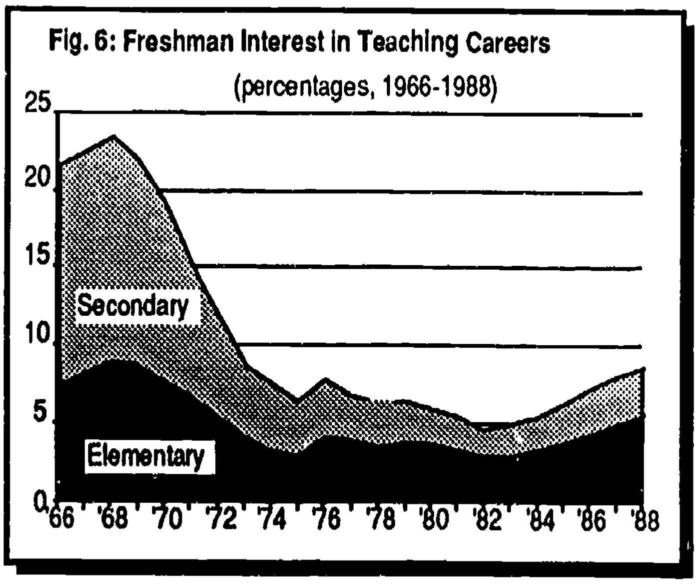


Fig. 6: Freshman Interest in Teaching Careers

(percentages, 1966-1988)

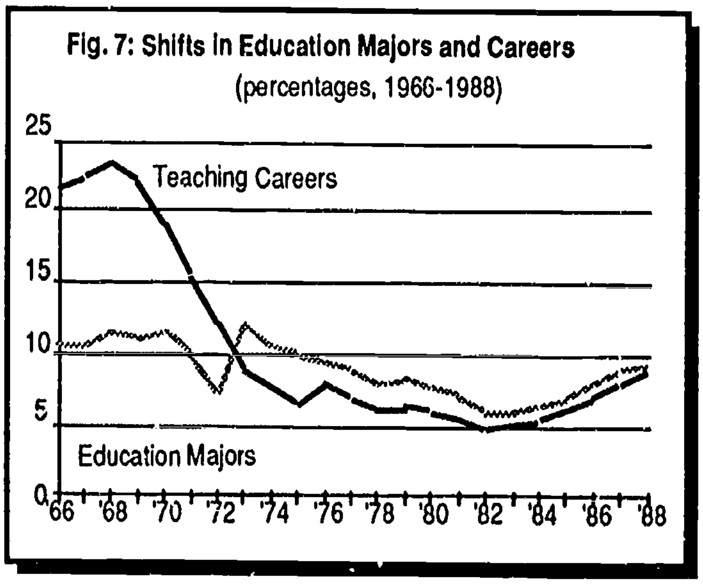


Fig. 7: Shifts in Education Majors and Careers

(percentages, 1966-1988)

credentialed teachers have more than just a bachelor's degree). However, pending a quick resolution of this debate — one that involves unions, education schools, state boards, and as well as other parties — the short-term consequences suggest that future secondary school science teachers may have more upper-division college credits in pedagogy than in physics.

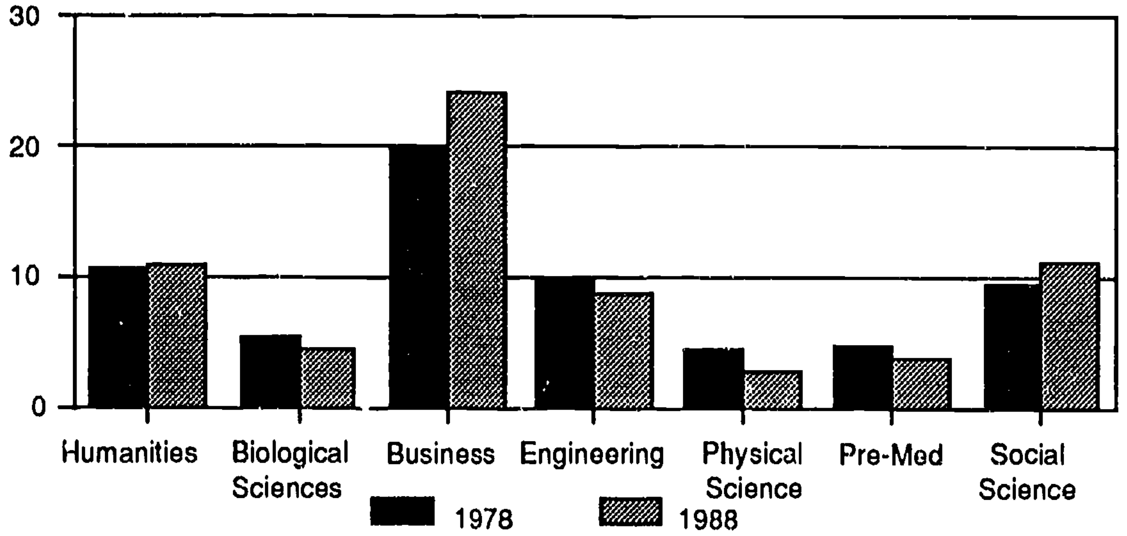
Teaching is a situation where the loss of the "captive population" of women has had dire consequences for the sciences. Two decades ago the young women who completed undergraduate science degrees often entered high school classrooms; today, the smaller number of science graduates now pursue careers in corporations or advanced training in medical programs and business schools. As women's aspirations and opportunities have increased over the past two decades we have lost a key resource in the pool of potential science instructors, as well as a key group of role models for women who might be interested in both the sciences and in secondary school teaching careers.

S/E Students In Four-Year Institutions

The data cited above reflect trends among *all freshmen in all institutions* (i.e., two-year colleges, four-year colleges, and universities). Let's now turn to CIRP data that profiles the population of first-time, full-time freshmen in four-year colleges and universities.[5]

Ten year trends point to a significant downturn in the the sciences among freshmen in four-year colleges and universities. These downturns for the science majors come as freshman interest in business and social sciences have increased by a one-fifth or more, and humanities and social sciences have also posted modest if steady gains (up by a tenth since 1978; Figure 8). In other words, even as some liberal arts majors show increases in student interest over the past decade, these gains in "market share" come at the expense of freshman interest in science majors.

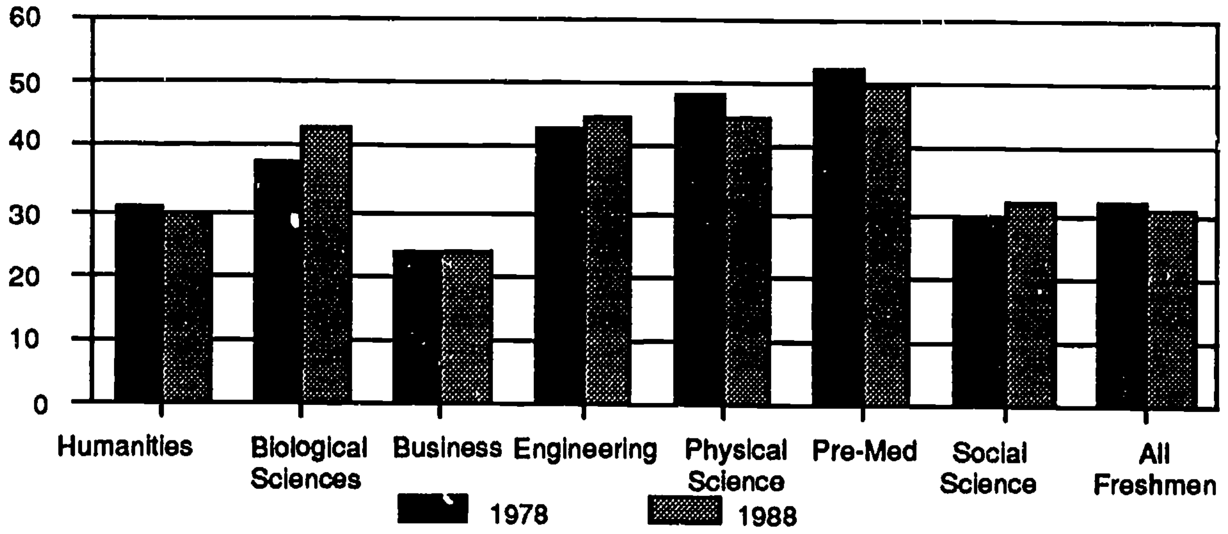
Fig. 8: Changes in Freshman Interest in Science Majors
(percentages, first-time, full-time freshmen in four-year institutions)



Although these declines in "market share" are troubling, the sciences continue to attract a disproportionate pool of academically able students. In 1988, 45.3 percent of the aspiring science/engineering (S/E) majors in four-year colleges and universities reported high school grades of "A" or "A-," compared to 26.3 percent for students planning non/S/E majors. And in contrast to the consistent declines in "market share" for the sciences, we do see some gains in the "talent share" of freshmen planning S/E majors (Figure 9). In engineering, the change in talent share (i.e., proportion of "A/A-" students planning engineering majors) between 1978 and 1988 increased by nearly one-quarter, 14.1 to 17.4

percent. Social science majors also reflect some gains modest gains in talent share (up about a tenth, from 8.8 percent in 1978 to 9.8 percent in 1988). There was no change in "talent share" among the life sciences during this period (at 7.9 percent in both 1978 and 1988).

Fig. 9: Changes in the "Talent Share" of Undergraduate Majors
(percentages for students reporting A/A- high school GPAs, 1978 and 1988)



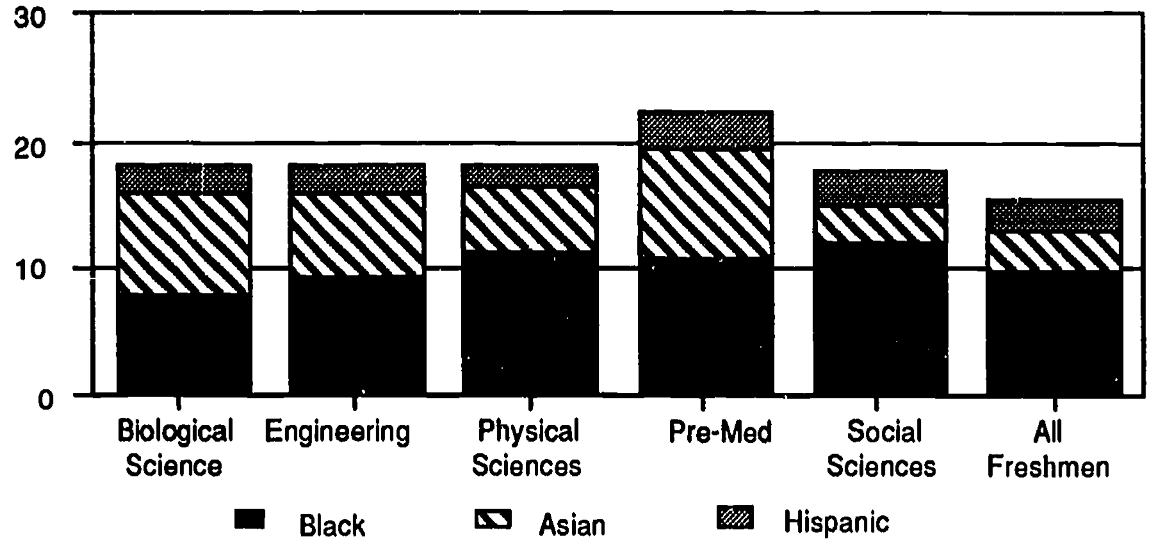
Unfortunately, physical sciences and pre-medical majors posted declines over the past decade, falling 18.2 percent and 10.5 percent, respectively. However encouraging, these proportional changes may, in part, overstate the real significance of these gains or declines. For example, the roughly one-tenth gain in "talent share" in the social sciences represents an absolute again of only 1.0 percent over ten years, from 8.8 to 9.8 percent.

Minority Students

The CIRP data on minority interest in the sciences suggest that there has been some improvement at the front-end of the pipeline over the past decade. Interest in engineering, physical science, and life science majors among Black and Hispanic freshmen all posted gains between 1978 and 1988. Moreover, in some cases these gains push minority students past many of the commonly-used measures of parity often employed to assess representation and progress (Figure 10). For example, Blacks represent 9.8 percent of the first-time, full-time freshmen enrolled in the nation's four-year colleges and universities in Fall 1978; however, Blacks also account for 11.5 percent of the freshmen planning to pursue physical science majors (e.g., chemistry, physics, mathematics) in Fall 1988. Similarly, Hispanic students represent 1.8 percent of the first-time, full-time freshman population this past fall and 2.1 percent of the aspiring freshman engineering students.

In short, these data suggest that the long-term, institutional, governmental, philanthropic and corporate investment to increase the traditional underrepresentation of Black and Hispanic students in the sciences is beginning to yield some real rewards. Of course these data reflect only shifts at the front end of the undergraduate pipeline; they do not tell us about the persistence rates and ultimate majors of science-oriented minority freshmen. And this will be an issue of growing importance given both the demographic declines and shifts of the 1990s as well as the small likelihood of any real gain in freshman interest in science majors in the next five or even ten years.

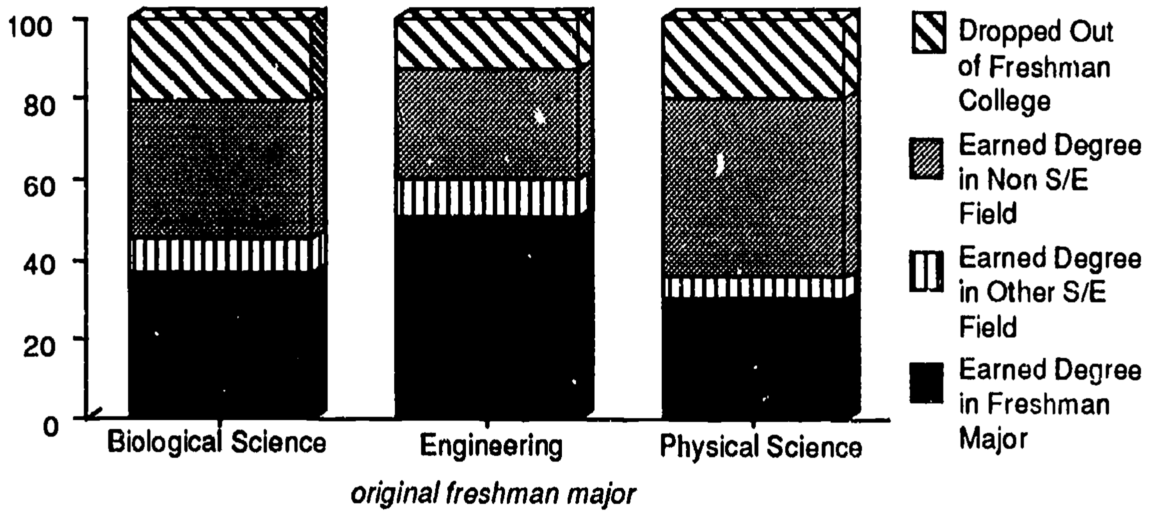
Fig. 10: Ethnic and Minority Student Interest in the Sciences, Fall 1988
(percentages, freshmen in 4-year institutions, Fall 1988)



Persistence and Degree Completion Rates for Science-Oriented Freshmen

Our longitudinal studies of freshman preferences indicate that a tremendous number of aspiring science majors ultimately "deflect" or migrate to other non-science fields (Figure 11). Indeed, the sciences have the highest deflection rates and lowest "recruitment" rates of any undergraduate fields.

Fig 11. Retention and Degree Completion Rates for Aspiring Science Majors
(percentages, 1982 freshmen in four-year colleges and universities)



In short, science departments lose a huge proportion of their potential "clients" or customers — academically-able and intellectually motivated students who enter college with a genuine interest in studying science. Given the high defection rates — the loss of potential clients — we could probably say most undergraduate science programs would probably be bankrupt if they were run as small businesses.

This "small business" analogy will probably be an anathema to most science faculty. Indeed, on many campuses science departments often take great pride in the number of students who "flunk out" of key courses in the lower-division sequence or who ultimately change majors. This has always a hallmark of the sciences: certainly organic chemistry has been a traumatic if not a career-shaping experience for hundreds of thousands of pre-med students over the years. Yet on many campuses there also seems to be almost an informal competition to see which (science) classes have the lowest grades or which programs have the lowest mean GPAs. However, any organization or enterprise that loses half or more of its potential clients may be in trouble. And these data should be especially troubling given that the sciences attract a disproportionate number of academically-able freshmen.

Where do they go? Most science aspirants leave for non-science fields, rather than dropping out of college completely. The path from engineering to business has been well-documented over the years on many campuses. Not surprisingly, the "defectors" usually do very well academically in their new departments

The Profile of Freshmen Across Science Majors

This far most of the discussion has focused on students within the sciences, as opposed to comparisons of students across the various science majors. However, the CIRP data reveal some very interesting differences *between* the populations of aspiring life science, social science, engineering, and physical science majors.

Degree Aspirations

The degree aspirations of all American freshmen have been increasing in recent years. Between 1980 and 1988, the proportion of all freshmen (in all institutions across all majors) planning to pursue some type of graduate degree rose by more than one-fifth, from 49.3 percent in 1980 to 59.0 percent in in 1988. During this period, freshman interest in the master's degree rose by one-fifth (from 29.7 to 36.3 percent), while the doctorate gained by almost half (from 7.9 percent in 19180 to 11.7 percent in 1988). Although these gains are notable, they mask the even more dramatic rise in degree aspirations among women over the past two decades. Between 1970 and 1988, the proportion of freshman women planning to pursue a doctoral degree increased by two-thirds (from 6.5 to 11.4 percent.) This compares to an ebb-and-flow pattern among men, beginning at 12.3 percent in 1970, falling to 8.5 percent in 1980, and then rising again to 12.1 percent in 1988 (Figure 12).The rise in degree aspirations suggest that a growing proportion of students feel that the

Fig 12: Doctoral Degree Aspirations Among Freshmen
(percentages, by sex)

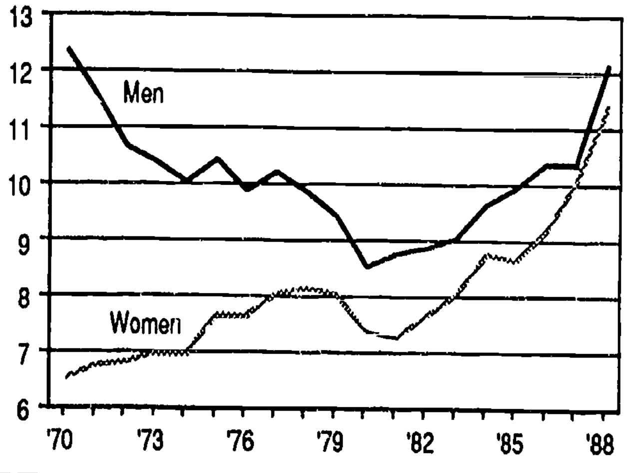
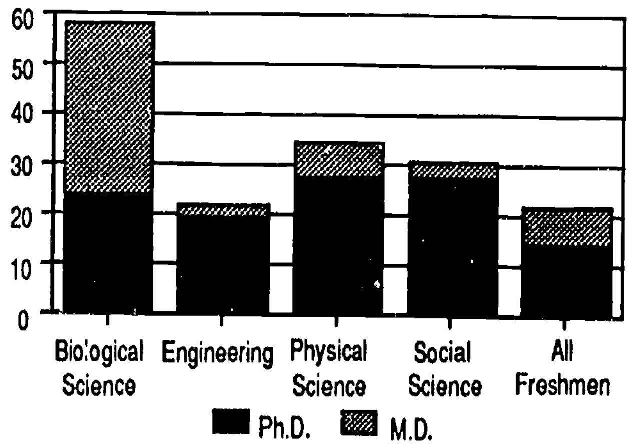


Fig. 13: Degree Aspirations of S/E Freshmen, Fall 1988
(percentages, first-time, full-time freshmen
in four-year institutions)



bachelor's degree will not provide adequate training or credentials for the demands of the job market of the next decade and on into the 21st century. Science students, in general, have higher degree aspirations than their peers in other majors. And there are interesting and important differences in the degree aspirations across various undergraduate majors. Not surprisingly, a large proportion of aspiring life science majors (about one-third) ultimately hope to pursue medical training (i.e., as physicians, veterinarians, or dentists; see Figure 13). Also not surprisingly is that a far smaller proportion of aspiring engineering and the physical science majors indicate interest in medical training.

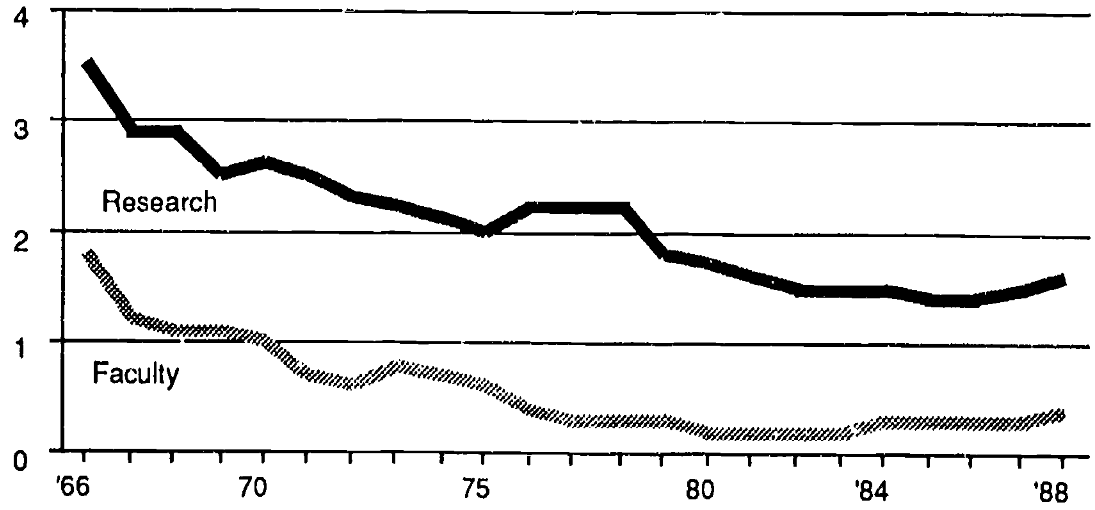
Interest in the doctorate among science students in four-year institutions has been rising over the past ten years, although in some instances this increase has been slower than the overall increase posted for all four-year college and university freshmen. Between 1978 and 1988, the proportion of aspiring engineers planning to pursue the doctorate grew by almost one-fourth (from 15.8 to 19.5 percent). Among biological science students the gain in doctoral degree aspiration was almost two-fifths (from 17.5 to 24.3 percent). The social sciences registered a gain of almost one-third (from 20.9 to 27.5 percent) over the past decade. Even the physical sciences and mathematics, which have been steadily dropping in freshman popularity over the past two decades, posted a gain of about an eighth (from 11.3 to 14.5 percent) during this period.

These recent gains in freshman interest in the doctorate may mark the beginning of the return of American students into *graduate* science and technology programs. Admittedly, we are dealing with freshman data which has many limitations. It is a long time and distance from undergraduate registration to graduate school matriculation. A large number of these students will change major, career choice, and degree plans during their undergraduate years. Many academically-able and very motivated science students will encounter various hurdles that will redirect their interest in and academic commitment to the study of science. The *defectors* -- students who leave the undergraduate study for other majors and careers — reflect a serious loss for the science pipeline. Additionally, the prospects of a low-paying assistantship and the arduous path through graduate school, coupled with the increasingly common post-doctoral experience will also channel many science and engineering graduates into the well-paying jobs increasing available to technical graduates upon completion of the baccalaureate.

Career Aspirations

The CIRP data also document a dramatic decline the proportion of entering freshman interest in faculty or research careers since 1966 (Figure 14). Freshman interest in faculty careers has dropped by more than three-fourths

Fig. 14: Freshman Interest in Faculty and Research Careers
(percentages, first-time, full-time freshmen in all institutions)



over the past 23 years, from 1.8 percent in 1966 to 0.4 percent in 1988. And interest in scientific research careers among entering students has fallen by half, from 3.5 to 1.6 percent during the same period. These declines come at a time when many observers predict future shortages in the pipeline of prospective college faculty and scientific researchers in the United States.

The CIRP data profiling science-oriented freshmen in four-year institutions points suggests that there has been a slight decline in student interest in research careers over the past decade, coupled with very slight increases in faculty careers. Of course these are difficult distinctions in the sciences, as many faculty are engaged in research. Were we to aggregate the faculty and research career preferences over the past decade, we find virtually no change in the proportion of science-oriented freshmen who plan to pursue faculty/research careers. However, the seemingly "steady state" of career aspirations among science students is not entirely good news. The market share of science students has dropped along with the overall decline in the size of the freshman age-cohort. Taken together, the decline in two key values affecting the denominator factor in the science pipeline equation offsets any stability or gain in the numerator factor. In other words, a steady "market share" in a declining market still means fewer people in the pipeline.

Student Values

It is an increasingly common pastime in the academic community to lament the seemingly "better times" of earlier eras. Faculty who began their careers just before or shortly after the Second World War often speak fondly about the more dedicated GI-Bill students who populated the nation's colleges in the late 1940s and early 1950s. More recently, those of us who were on college campuses as undergraduates, graduate students, or faculty during the tumultuous period of the late 1960s and early 1970s engage in our own version of this game. We frequently compare today's students against the "60s generation." In general, we find today's students guilty of a number of sins of omission and commission.

What are the particular complaints commonly leveled against today's students? Without attempting to rank the alleged sins by the seriousness of the potential offense, academics often describe today's students as:

- *greedy and materialistic*, preoccupied with making money, and making it fast.
- *intellectually docile*, demonstrating more concern about their grades than about challenging intellectual issues.
- *ambivalent if not outright apathetic about pressing social issues and commonweal concerns*, devoting more time to make life better for themselves and doing little that might benefit others.

Certainly some of widely publicized data from the CIRP surveys provide some support for this perspective. More than three-fourths of todays' freshmen identify "being very well-off financially" as an "essential" or "very-important" life goal, up from less than two-fifths in 1970. And a record 72.6 percent of the 1988 freshmen indicated that "making more money" was a "very important" factor in their decision to attend college (Figure 15).

Are science students very different from their peers on some of these issues? Although the aspiring business students are the most likely to endorse the relationship between money and college, engineering majors rank second among 7 student subgroups in endorsing the "money factor" as a key issue in the decision to attend college (Figure 16). Moreover, aspiring engineering students — like their peers in business -- are less interested in the "general education" aspects of a college education than students in other science (and non-science) majors.

In other words, aspiring engineers (like aspiring business students) seem to view their college experience as a period of "technical training" and "portfolio" development — for building the foundations of a career— than as a time for broad learning and personal development. Freshmen planning other science majors seem to be less concerned about money than aspiring engineers and somewhat more interested traditional notions of "liberal education."

Fig. 15: Reasons for Attending College
(percentage of entering freshmen indicating "very important")

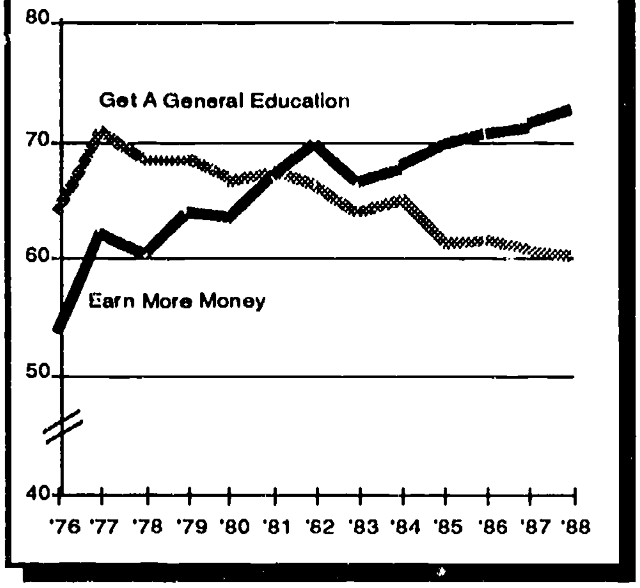
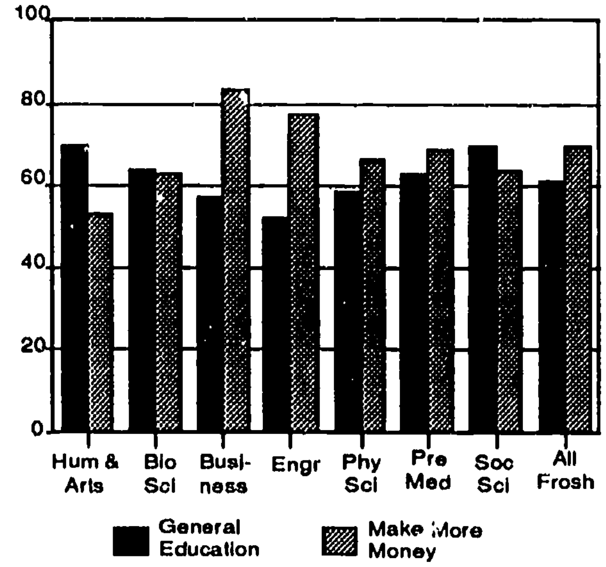


Fig. 16: Reasons for Attending College, by Major
(percentages, first-time, full-time freshmen in four-year institutions by intended major, Fall 1988)



Yet despite the CIRP data and other indicators, it may be premature dismiss today's students as "greedy materialists." Their behaviors and values demonstrate, in part, a readjustment of priorities and a reflection of their perceptions on the world. Today's students are the children of an economic upheaval. They came of age — into adolescence and early adulthood — during a period marked by the high inflation of the late 1970s, the severe recession of the early 1980s, and the current restructuring of the American economy. Their economic experience has been marked by upheaval and inconsistency rather than growth and stability. Their understanding of aspirations in the context of the American postwar experience — of attaining if not surpassing their parents' economic accomplishments — is under attack.

The *key symbols* of family economic aspirations — owning a home and sending children to college — increasing seem to be the perogative of the rich, or at least to require what today's students' perceive to be as "real wealth." And today's students implicitly accept that it will take the efforts of two working parents to provide the comforts and security that they may have experienced as the child in a family of only one working parent. We may be offended by their talk about making "lots of money" and being well-off financially. However, we must recognize that the basis of their economic perspective is very different than the one that marked the 1950s and 1960s. The world view of today's students is more like that of their grandparents who experienced the Depression of the 1930s than that of their parents who grew-up during the economically prosperous 1950s and 1960s. The CIRP data document behaviors and attitudes — the shift to business majors, the concern about being well-off, etc. — that reflect a fundamental insecurity about the economic future.

The irony in this behavior, of course, is that demographic forces bode well for these students. These are also the children of the "baby bust." .Demographic forces alone suggest that they will enter the best job market the nation has seen for the past 30 years. We already see indicators of this in the "help wanted" posters in most shops, fast food restaurants, and department stores. Yet their outlook and behavior seems unaffected by the rational presentation of demographic and economic data. In short, today's students are scared, risk-aversive, and insecure.

The New Challenges for Undergraduate Science Education

Undergraduate science education confronts some major challenges in the coming decade. The CIRP data point to four fundamental issues which should concern educators and policymakers:

Talent Development

The talent pipeline and science talent development is a critical issue for science these days. Each year tens of thousands academically-able and well-motivated students enter college planning to pursue science. There is a tremendous talent loss that institutions and programs need not incur — and that the nation probably can no longer afford. Admittedly this is not now a new problem: the sciences have long experienced high defection rates. However, the decline in both the numerator and denominator variables in the science pipeline suggest the nation can no longer afford this talent loss. The solution, of course, does not mean pandering to students by reducing expectations about academic performance. But we should recognize that departments and programs need to develop an environment that encourages students to pursue the sciences, one that is perceived as encouraging rather than hostile. The increasing external pressures on institutions to conduct various outcomes analyses may be helpful in this context.

As part of institutional efforts to gain control over the growing assessment debate, campuses will have to identify various outcome measures as part of accreditation and program review activities. Data collection that provides information back to departments will be particularly helpful. The key data about program quality and student outcomes are not limited to post-test measures on cognitive examinations or department grading curves. Deans, faculty, and program chairs should be asking hard questions about recruitment, defection, and persistence rates among aspiring science students. These data contribute as much (if perhaps not more) to an understanding of program quality and outcomes as the traditional testing approaches.

Opportunities for Non-Science Students

Second, we need to provide more opportunities and encouragement for non-science students in the sciences. Science is a key resource for people in a variety of different sectors. Pharmaceutical companies need people who understand biochemistry and market demographics. We need to forge links between science training and public policy. There are a number of different options campuses and programs could pursue. Some may not necessarily require the traditional science major. For example, twenty years ago most campuses offered a recognized minor, a separate and important upper-division concentration in an academic discipline other than the student's major. This is but one possibility; certainly there are others. Most important, however, is that these new options involve more than students working their way through (or around) a lower-division curriculum model based on distribution requirements. And part of the responsibility expanding these opportunities falls on the science departments and faculty, who must be genuinely willing to make the opportunity available.

Student-Faculty Interaction

Third, we need to know more about the relationship between undergraduate science students and undergraduate science faculty. The discussion prompted by the Oberlin reports about the "science productivity" of small teaching colleges highlights the key role of faculty in the talent development process. Unfortunately, most of the research about talent development usually ignores the interactive affects in student outcomes (for example, retention rates in selected majors): most pipeline studies focus exclusively on students and rarely on the key role of faculty behavior and attitudes in defining a learning and mentoring environment.

Consequently, we know very little about the interaction between faculty and students within individual disciplines. We've got some fairly conclusive data about the interaction affects at the "macro" or institutional level: we know that contact with faculty is a very important factor in the context of career choice, satisfaction with college, persistence, and academic performance. But we know comparatively about how the faculty factor plays itself out in the individual disciplines. And this should be very important information for the people in the sciences.

Science in Secondary Schools

Finally, we must acknowledge the pressing need to bring science — and science students — back into secondary school classrooms. We need to explore various program alternatives, degree structures, curricular options, certification procedures, and financial incentives to encourage undergraduate science majors to pursue careers as junior high and high school science and mathematics teachers. We desperately need this talent back in our classrooms if we are to rebuild the infrastructure which will support the science personnel pipeline that has contributed to the nation's research capacity and economic development during the postwar era.

The sciences play an important role in the life and progress of the nation. Science and technology are the engine that will drive the American economy in the 21st Century. There is much we must to do to help maintain that engine. Certainly one key factor is recognizing the pipeline issues in the sciences. The CIRP data presented here provide important information that can help faculty, institutional officials, and government policymakers address some of the critical issues affecting the science pipeline in the next decade and the next century.

Endnotes

1. Keynote presentation, Sigma Xi Conference on Undergraduate Education in Science, Mathematics, and Engineering at the Wingspread Conference Center, Racine, WI, on January 23, 1989. This presentation was supported in part by funds from Sigma Xi and from a grant to Sigma XI from the National Science Foundation. The views expressed in this paper are solely those of the author and do not necessarily reflect the official position of the sponsoring groups. © Kenneth C. Green, 1989.

2. Most of the science-oriented data presented here focus on first-time, full-time students enrolled in four-year institutions. Although the CIRP does include community college students in the survey population, full-time students now comprise a less than half of the "undergraduate" enrollment in two-year institutions. Consequently, any CIRP-based portrait of the science interests of students in two-year colleges and pipeline capacity of community colleges would not provide a complete picture of two-year college sector.

3. References to the freshman population refer to first-time, full-time students, i.e., "modal" or traditional students. The CIRP data base automatically excludes those freshmen who are not enrolled as full-time students, and/or those students who have had some prior degree credit experience. See Astin et. al, 1988, Appendix A, for details about the CIRP survey methodology.

4. The CIRP data do predict future trends in the number of earned undergraduate science degrees. Internal studies conducted by CIRP staff point to very high correlations (r^2 values) between the proportion of freshmen planning to major in scientific fields and the number of earned undergraduate science degrees four years later (i.e., a four-year cohort approach). These r^2 values range from 88 for the biological sciences to .93 for engineering to .98 for computer science.

5. As full-time freshmen represent the less than half the enrollments of entering students in the nation's two-year colleges we have not included two-year students in profiles presented in the next sections.

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