PRESIDENTIAL ADDRESS

PRIMING THE PUMP IN MATHEMATICS AND SCIENCE EDUCATION

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INTRODUCTION

The math and science pipeline might be described as the sequence of educational levels leading to advanced degrees in math, science, and technology fields. I prefer to think of the system as more of a pump; hence I've entitled this talk "Priming the Pump." Admittedly it frequently functions as a sieve, but we must fight that and work on making it work as a pump. The components of the system are similar to, and at lower levels overlap, the pipelines to other advanced degrees. As visualized in Figure 1, this pipeline, or pump, or wellhead system, has many interdependent parts. A broader perspective might be to visualize the whole water cycle -- the slowdown of any part affects the whole. Problems and successes at primary school levels impact secondary, which in turn impact undergraduate, etc. Undergraduate programs in teacher training are particularly important in priming the pump at the lower levels. And, of course, all levels feed back into the system when we function as parents.

Today, I'm going to try to tie together some of the evidence about our pipeline, which has come to my attention over the last three or four years. You will, hopefully, already be familiar with some parts of this. However, I believe most of you can benefit, as I did, from having things drawn together. Four years ago, I became Chair of the Department of Mathematics and Natural Sciences at Northern State. One of the advantages to me personally was that I was forced to deal with a variety of problems and opportunities outside my own field of expertise. Previously, I was simply teaching my own botany and general biology courses, and doing research on seaweeds. I was blissfully, but perhaps inexcusably, ignorant of what has been going on in education all around me. Things are **not** the same now as when

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most of you, and I, went to school -- and while I am older than many in this audience, I am also younger than many. We must realize that we share common problems with our colleagues across the curriculum, as well as in related disciplines. We must work together to solve them. The system is too interdependent for us to be narrow in focus. I'd like to thank my colleagues at NSU and elsewhere around the state and country for broadening my view. Meeting with the chemists or the mathematicians in my department to address problems in those disciplines is something not every botanist has the opportunity to do.

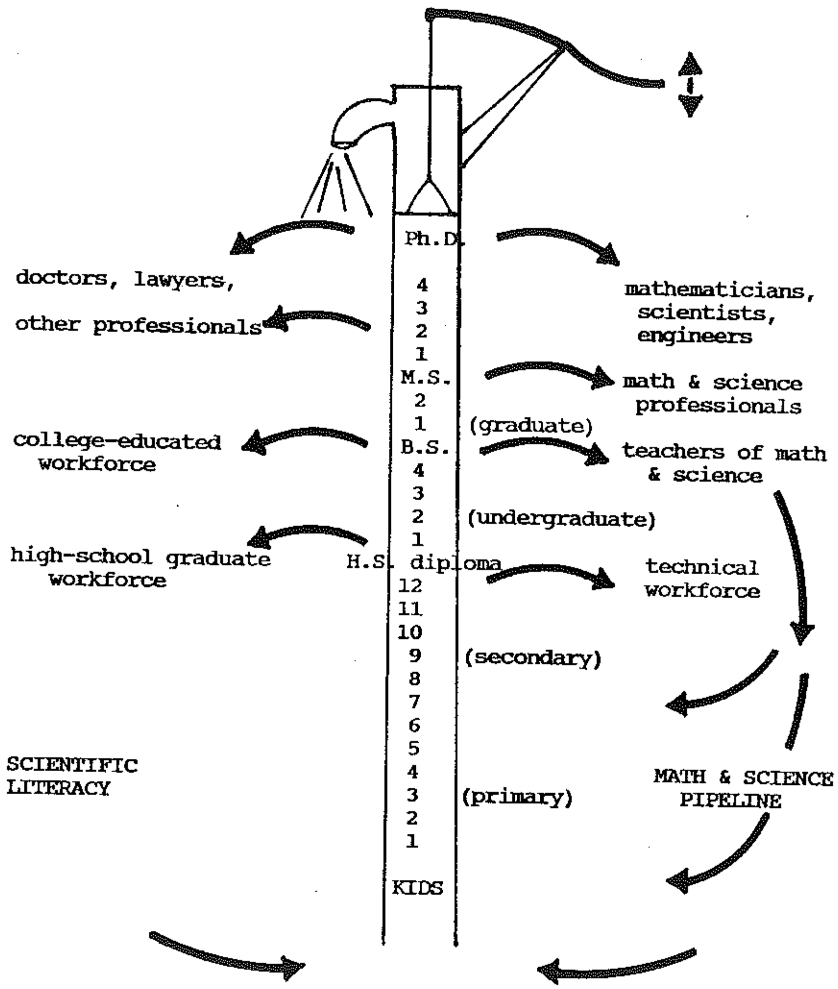

Figure 1. The math and science pipeline, or pump.

My plan for this talk is to review:

I. Some documentation of the problems in the math and science pipeline, using a series of overheads borrowed in 1989 from Dr. Bassam Shakashiri, formerly NSF Director of Education.

II. Some analysis of interesting findings from Astin and Green's data on American freshmen, obtained in the Cooperative Institutional Research Program.

III. Conclusions in *Science for All Americans*, which spell out broader trends in scientific literacy for the whole populace.

IV. "Fundamental Topics" which must be addressed in improving the system, from Sigma Xi's 1989 Wingspread Conference.

I have handouts of my bibliography of this talk -- since the data clearly is not mine. I want to be sure the sources of this information are recognized and made accessible to you.

PROBLEMS IN THE PIPELINE

The following information is from a series of overheads, courtesy of Dr. Shakashiri, and are based on figures from a variety of sources including the National Science Foundation and the Department of Education.

Data on the number of 22-year-olds in the U.S. showed a peak in about 1980-1982, and another smaller peak anticipated in 2004-2009. In higher education, we are working with declining numbers, but the students representing the peak expected in the first decade of the next century should be entering the bottom of our pipeline about now. They will be strongly influenced by changes we are making **today**.

I am not one who worries much about our rank as a world power -- I would prefer we think about emphasizing worldwide education. However, I find it interesting that the United States ranks 8th among countries of the world in Grade 5 science achievement but only 15th by Grade 9. This surely tells us that something is wrong. Conventional wisdom says that if you haven't caught a child's interest in science by about 5th grade, you won't. That doesn't mean we shouldn't try later -- it just emphasizes the importance of the early educational experiences in supplying the bulk flow coming up the educational levels of our pipeline.

Looking numerically at the pipeline, using NSF's figures, we see that of about four million high school sophomores in 1977, about 340,000 entered college expressing interest in natural sciences or engineering; about 206,000 took B.S. degrees in those areas (I bet that's a better ratio than we get in South Dakota), about 61,000 became graduate students, about 46,000 earned M.S. degrees in 1986, and 9700 Ph.D.'s are expected in 1992. With the narrowing of the pool at each level, it becomes clear how important it is to prime that pump at the bottom end. Similar information shows that the interest level of minority students is especially dismal: proportionally even fewer are interested in math and science entering college. The situation is better for women than for minorities as a whole, but it is still too low compared to figures for men. Of about two million male high school sophomores in 1977, for instance, about one quarter expressed interest in natural sciences or engineering. Of a similar number of about two million female students, fewer than one eighth expressed similar interests. These figures are particularly distressing when you realize the increasing importance of women and minorities in the student population. These students are the new majority.

Figures on the annual production of Natural Science and Engineering degrees from U.S. institutions indicate increasing shortfalls compared to demand, projected over the next two decades. Foreign students are currently picking up some of that slack -- as the rest of the world continues to recognize the excellence of our graduate programs. But NSF does not expect the contribution of foreign students to increase further, and expects the shortfall to widen. Admittedly, there is some controversy about the magnitude of the expected shortfall. I would like to interject here that these data are paralleled by the data on scientific literacy for the population as a whole. An article in *American Demographics* (Miller, 1987) pointed out the abysmal understanding of our world by high school drop-outs. These are a large portion of our blue-collar workforce in an increasingly technological age. We need to recognize that many students never see college. Their only exposure to science is in K-12. They are also a major component of our societal problems, as indicated by figures showing that 80% of prisoners in jails are high school drop-outs. I doubt much has changed since 1987. The implication is that a little money invested in education of these students might save a lot of money in social expenditure, as well as in wasted lives.

AMERICAN FRESHMEN

Assuming I've convinced you that there is a problem in the pipeline, let's look at some of the results of the surveys by the Cooperative Institutional Research Program (CIRP). From 1966 to 1985, CIRP surveyed six million students. They continue to survey about 200,000 freshmen each year at 550 two-year and four-year colleges throughout the U.S. The information in the following paragraphs is from Astin and Green's 1987 summary: *The American Freshman, Twenty Year Trends, 1966-1986.* Most of the differences we see in the graphs of the data presented are statistically significant because of the huge numbers of students surveyed. Most of the data supports the opinions expressed every day by college professors, sitting around the coffee table. However, you may find a few surprises.

Student self-ratings are based on a series of questions in which students rate themselves relative to their peers. In all areas but one, the students were more likely in 1985 to rate themselves above average than in 1966. They rated themselves higher in 1985 in artistic ability, drive to achieve, leadership, math ability (surprise -- maybe they think they can't do math, but at least they do it better than most of their peers?), popularity, self-confidence, and writing ability (another surprise?). Note, I am emphasizing the trends. Even though the math ability rank has gone up, we still have less than 40% perceiving themselves as above average in mathematics ability. Despite the above, the students rated themselves lower overall in academic ability in 1985 than in 1966.

Grade inflation touches a nerve with a lot of college faculty, including me. I feel grade inflation in the high schools has really hurt college students. Average students come to us with "A" averages from high school. At least in math and science, college grade inflation hasn't kept up with that in high schools. So, many of our students earn solid, respectable B's, then feel like failures. These students may make excellent mathematicians and scientists, but no one has told them so. They need our support and encouragement. They know that they didn't have to work for those A's in high school, so they don't know what they are capable of doing. According to the CIRP survey, most college freshmen "agree strongly or somewhat, that grading in the high schools is too easy." (Astin and Green, 1987)

There has been an overall drop in freshman interest in proceeding to the doctorate. However, this is an almost exclusively male phenomenon, which swamps out the slight increase for women. Interest in the doctorate dropped, for men, from a little over 12% in 1970 to about 9% in 1979 and about 10% in 1985. For women, there was a rise from a little over 6% in 1970, to about 9% in 1985. Freshman interest in medical degrees peaked in the early 70's, then dropped sharply. However it continues a slow rise for women. Perhaps women who would have been nurses twenty to thirty years ago are now aspiring doctors. Again, the overall drop is primarily among freshmen males. Lest you think these trends are unique to the sciences, the pattern for interest in law degrees is almost identical. Personally, I am a great advocate of rising aspirations for women, and these data are encouraging in that respect. However, I am deeply disturbed at what they show happening to male students. We must work to reverse the declines in aspirations among our young men.

I think most of us have felt, almost intuitively, that the loss in interest in math and science, as well as other traditional liberal arts, is correlated to the rise in business degrees. This is borne out by the data, with two exceptions to this pattern in engineering and computer sciences. These peaked in the early 80's. Within the sciences, most of the drop has been in mathematics and physical sciences. There was a sharp peak in interest in the biological sciences in the late 70's, but that has also petered out. While business has risen, it surely doesn't account for all of the **80%** drop in students interested in majoring in mathematics, from a peak of about 4.5% in 1966 to less than 1% in 1985.

Measures of career preferences show similar patterns but add some interesting facets. There was a precipitous decline in student preference for teaching careers after a peak of around 23% in the late 60's, to a low of about 5% in 1982. There was a little rise in the 80's, but nothing that could be called a recovery. Again, we can learn something about this drop by comparing data for men and women. Both have dropped, but the decline for women has been amazing. In the 1960's, 40% of females and 12% of males wanted to be teachers. In 1985, that had dropped to 9.5% of females, and 2.6% of males. I once heard a speaker at the Sigma Xi meetings in Denver in 1989 call this the "loss of the captive female population." Thirty years ago, a bright, intelligent woman had two main career options: nursing or teaching. The women's movement has opened thousands of doors to better-paying, more highly respected jobs. We certainly have some excellent students still choosing to be teachers -- and we simply must cherish them. However, I think everyone working in the field realizes that the average prospective teacher is not one of our "best and brightest." A slightly different way of looking at the data involves comparing career preferences for women through this period. We see a great decline in interest in teaching but increases in interest in business, law, medicine, and engineering.

The CIRP study also demonstrates some disturbing changes in student values and goals. In 1967, over 80% of students considered the goal to "develop a meaningful philosophy of life" as "very important or essential." This compares to fewer than 45% in 1985. On the other hand, the goal to "be very well off financially" was considered "very important or essential" by 40-42% in the early years of the study (1967-1970) but by 1985 had risen to fully 70%. Astin and Green (1987) summarize the trends as showing increases in those goals that involve "money, power, and status," while decreases are seen in goals related to "social concern and altruism."

There is a lot of other fascinating information buried in the CIRP data, and I hope you'll spend some time with it. For the purposes of this talk, they indicate (1) a major shift in female choices, (2) a surge in interest in business accompanied by major declines in interest in teacher education and in the traditional arts and sciences, especially among male freshmen. I've shown the data for teaching, and for mathematics and science, but the figures are nearly as bad for English and foreign languages.

SCIENTIFIC LITERACY

I don't really have time to discuss much about the AAAS Project 2061 report, *Science for All Americans* (1989). However, I hope you will make a point of reading its summary, and at least those sections which apply most directly to your particular field. This is especially important as we in South Dakota revise and modify college and K-12 curricula in math and science. While this publication emphasizes the value of science to the "average" citizen, I would like to use the same points to emphasize the value of broad-based science education for all students, including those choosing to major in math, science, or engineering. We must not lose sight of the fact that our scientists must also be scientifically literate across our curriculum. At NSU, for instance, a student majoring in math takes physics but has no exposure to the ideas of biology or chemistry or earth sciences. Perhaps because of deficiencies in the high school science curriculum, they end up scientific specialists -- seeing some of the trees in great detail but not knowing the forest is even there. For instance, some majors in math and physical sciences understand less about the theory of evolution by natural selection than do most creationists. I am personally an advocate of a freshman-level natural science sequence for **all** students -- including prospective math and science majors. I see the problem as less severe for biology majors because they take at least some college-level math, chemistry, and often physics. But other areas of science may be turning out students who are no more "scientifically literate" than the general populace. From *Science for All Americans*, let me quote the definition of scientific literacy, from page 4:

> *Science for All Americans* is based on the belief that the scientifically literate person is one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes.

I feel this is very important for science students as well as non-science students. *Science for All Americans*, page 5, recommends:

> To ensure the scientific literacy of all students, curricula must be changed to reduce the sheer amount of material covered; to weaken or eliminate rigid subject-matter boundaries; to pay more attention to the connections among science, mathematics, and technology; to present the scientific endeavor as a social enterprise that strongly influences -- and is influenced by -- human thought and action; and to foster scientific ways of thinking.

That's a tall order. This book also has an excellent bibliography of additional studies in these areas. OK, so what should we be looking at in our revisions to the way we are doing things now?

FUNDAMENTAL TOPICS

If we agree we must make changes, how shall we organize our thoughts about that change? I suggest we use as a guide the Fundamental Topics listed in the Wingspread report by a committee of Sigma Xi -- the Scientific Research Society. A couple of years ago we at NSU used this publication as a basis for organizing our departmental missions and goals statement. They list seven fundamental topics, of which I will discuss the first three.

Fundamental Topic One: Quality of Instruction

> 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.

Personally, I believe that part of the reason for this may be the difficulty in evaluating "good teaching." Whatever the reason, I think we can accept as fact that nearly all university-level tenure committees, even at the smaller institutions like NSU and others in South Dakota, will be looking first at research or scholarship, which is easier to measure. I'm not saying this is all bad; I happen to believe there is a positive correlation between good research and good teaching. But we all know of exceptions. At present, our teaching is only really evaluated if it is terrible or incompetent. If we are even marginally competent, we are not rewarded for putting extra effort into improvement.

Fundamental Topic Two: Quality of Curriculum

> 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.

This reminds me of the "Calvin and Hobbes" cartoon, where Calvin is sitting at his little desk studying (a novel situation in itself). He says "A bushel is a unit of weight equal to four pecks." Calvin turns to Hobbes, his tiger, and asks "What's a peck?" Hobbes replies, "A quick smooch." The next frame shows Calvin in great thought. Finally, he turns to Hobbes and says "You know, I don't understand math at all." (Universal Press Syndicate, 1986)

To continue the quote from Wingspread:

> 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 high school. The National Advisory Group identified entry-level courses in science, mathematics and engineering as 'watersheds'....

In short, the courses are either too hard or, if easy, too boring. I find that these courses now cover the same stuff we had in school, despite the information explosion. We need content. I am convinced that students cannot learn to think if they have nothing to think about. But we need to evaluate what content is likely to be important and to aid in understanding, and what is merely memorization which they will forget after the exam anyway.

Fundamental Topic Three: Quality of the Human Environment

> 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.

Personal observations: I teach 185 students in Biology 101 this semester. I feel this is too many, even though they have a 24-student laboratory session as part of the course. However, last week I had a conversation with Dr. Alan Meltzer of Renssalaer Polythechnic, about handling large courses. His freshman astronomy course has 600 students! We at NSU are very proud of our recent graduates and where they have gone, the jobs they have taken, the graduate schools they have chosen. Those graduates show that we provide a good education. But we still lose too many from the freshman majors courses, students who come to college with at least some interest in mathematics or sciences. I'm sure those of you from other parts of the state feel the same.

In the interests of time, let me just list the other "Fundamental Topics" covered in this report:

"Fundamental Topic Four: Quality of the Physical Environment" deals with classrooms, equipment, laboratories, technology, etc.

"Fundamental Topic Five: Accessibility and Flexibility of Curricula Essential for Student Mobility" addresses the problems of students changing majors or transferring between schools.

"Fundamental Topic Six: Attitudes and Perceptions of Students, Faculties, Administrations and the Public" discusses the relatively poor job that scientists as a whole have done in public relations.

"Fundamental Topic Seven: Promises and Special Needs of Traditionally Under-Represented Groups in Science, Mathematics and Engineering" points out our obligations to the new majority, consisting of women, minorities, the handicapped, and those with learning disabilities.

The Wingspread Conference concluded that "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," and that "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."

Let us return for a moment to my original model of the pump (Figure 1). Think of the cycle and your part in it. Think of the changes you would like to see made. Think of the things you'd like to do. Think of the things you'd like someone else to do. Then think again of what you want to see done, and where your own priorities fall in this scheme. Opportunity knocks, in South Dakota just now. We have Eisenhower funding; we have NSF Statewide Systemic Initiative funds; and moves are afoot to make major changes in teacher preparation. There will be lots of things changing over the next few years, and we can choose to be part of those solutions, or remain part of the problem. I recommend that you consider participating in the Saturday afternoon workshop on the Crisis in Math and Science Education, at which Dr. Katherine Pedersen, of the NSF-SSI program, will speak. Hopefully, over the next two days you will get psyched up, or primed, to get to work even harder on your own pump handle. A phrase from an Ann McCaffrey science fiction novel I read last week sums this up for me. "If not you, who?"

LITERATURE CITED

American Association for the Advancement of Science. 1989. *Science for All Americans.* AAAS, 1333 H St. NW, Washington, D.C. 20005.

Astin, A. W., and K. C. Green. 1987. *The American Freshman, Twenty Year Trends, 1966-1985.* Cooperative Institutional Research Program (CIRP), UCLA, Los Angeles, CA.

Miller, Jon D. 1987. The Scientifically Illiterate. *American Demographics* 9(6):26-37.

Shakhashiri, Bassam. 1989. Personal Communication.

Sigma Xi. 1989. *An Exploration of the Nature and Quality of Undergraduate Education in Science, Mathematics, and Engineering.* National Advisory Group, Sigma Xi, The Scientific Research Society, report of the Wingspread Conference. New Haven, CT 06511.

ADDITIONAL BIBLIOGRAPHY

American Association for the Advancement of Science. 1990. *The Liberal Art of Science: Agenda for Action.* AAAS, Washington, D.C. 20005.

Labarbera, M. 1989. *The Natural Sciences Sequence at the University of Chicago.* The Joyce Foundation and Sigma Xi.

Lohmann, J. R., and A. M. Stacy. 1992. *America's Academic Future: A Report of the Presidential Young Investigator Colloquium on U.S. Engineering, Mathematics, and Science Education for the Year 2010 and Beyond.* Directorate for Education and Human Resources, National Science Foundation.

Madison, B. L. 1990. *A Challenge of Numbers: People in the Mathematical Sciences.* Executive Summary. National Academy Press. Washington, C.C.

National Research Council. 1990. *Renewing U.S. Mathematics: A Plan for the 1990's.* Executive Summary. National Academy Press. Washington, D.C.

National Science Foundation. 1989. *Report on the NSF Disciplinary Workshops on Undergraduate Education.* Directorate for Science and Engineering Education, NSF. Washington, D.C.

Taylor, V. L. 1983. *How to Hold Students.* Key Productions. P.O. Box 525, Chatham, IL 62629.