Written Contributions to the EHR Advisory Committee Public Hearing on Institutional Perspectives

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Invited Speakers:
"Institutional Perspectives on SME&T Undergraduate Education"

Listed in order of Testimony. Titles indicate the speakers' positions at the time of the Hearing.

Grinnell College *Grinnell, Iowa*	**Pamela A. Ferguson** *President*
Emory & Henry College *Emory, Virginia*	**Thomas Morris** *President*
Onondaga Community College *Syracuse, New York*	**Bruce H. Leslie** *President*
St. Louis Community College *St. Louis, Missouri*	**Gwendolyn W. Stephenson** *Chancellor*
American Association of Community Colleges *Washington, District of Columbia*	**David R. Pierce** *President*
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University of Maryland, College Park *College Park, Maryland*	**William E. Kirwan** *President*
American Association of Colleges & Universities *Washington, District of Columbia*	**Paula P. Brownlee** *President*
New Jersey Institute of Technology *Edison, New Jersey*	**Saul K. Fenster** *President*
Portland State University *Portland, Oregon*	**Judith A. Ramaley** *President*
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Institutional Perspectives of College and University Leaders on Undergraduate Education and the National Science Foundation

Pamela A. Ferguson

President, Grinnell College
Grinnell, Iowa

We must ask three questions as we reckon with the worth of existing programs and entertain the addition or expansion of others:

1). What does the nation need in its workforce and its scientists?

2). What does NSF have to do with filling this need?; and

3). How does undergraduate education relate to the nation's needs and NSF?

I will try to paint the picture as most of my colleagues and I see it. A vital workforce for the 21st Century is peopled with the technically literate, inquisitive, and entrepreneurial in spirit. It is this workforce that will discover new technologies, use these technologies, and keep us as a major contributor to the betterment of this nation and the global community. Undergraduate education is not an auxiliary enterprise – it is a conduit and the birthplace for most scientists and a significant portion of the workforce.

NSF has successfully created a research infrastructure in which people are stimulated to have new ideas, with the confidence that, if their peers find an idea meritorious, funding will be provided to explore the idea. This is consistent with NSF's mission to provide the nation with both scientific knowledge and scientists – it is consistent with the nation's need to be a competitive force in an ever-changing, technologically sophisticated world.

This same infrastructure which enables and promotes people to take risks to do interesting things must be further developed for the undergraduate sector. We need to improve undergraduate science education so that our workforce is technically literate as well as to train the small percent who will be future scientists – including those few who will join the likes of Tom Cech (a Grinnell alumnus who recently received the National Medal of Science) or the late Robert Noyce (a Grinnell alumnus who co-invented the integrated circuit). Science education should be an embodiment of the entrepreneurial spirit because staid teaching begets staid students.

NSF can make a difference with funding and programs that are responsive to innovative ideas coming from the teaching community. It needs to support faculty and students the way it supports researchers because the undergraduate sector is the source for the researchers as well as educational citizens and multitudes of workers. One example of an extremely successful program is the Instrumentation and Laboratory Improvement (ILI) program, which provides modest support for instrumentation for teaching. In effect, however, it catalyzes major curricular renovation. The ILI program has been evaluated several times and has received glowing reviews.

In the ILI program, dollars are highly leveraged. A minimum of 50 percent of the funding must come from non-federal sources. Furthermore, no funds are provided to support personnel to actually develop experiments making use of the new instrument. There are other leveraged aspects to the program. Other faculty at the institution will notice the instrument, learn to use it, and devise unforeseen curricular changes. Furthermore, students and faculty involved in research projects will undoubtedly use the instrument. Faculty (either formally through publication or informally) tell their colleagues at other institutions of their successes and encourage them to mount similar efforts.

DUE has done a remarkable job, especially considering that funding was cut to zero dollars in the early 1980s. Since then, they have developed several programs that serve the community well. To address the issue of teaching and learning science at the undergraduate level, three areas need attention.

First, research and teaching still remain divorced at NSF. The programs, which support undergraduate research, are not cognizant that among the most important products of research at undergraduate institutions are the students. At an undergraduate institution, research not only contributes to the scholarship in a field, but it is a tremendous learning ground for students. Students learn, by doing science, what it is to be a scientist, how to ask questions, how to deal with the many obstacles that inquiry presents and the exhilaration of discovery.

Currently, NSF REU and RUI support is targeted only at the most elite institutions. It effectively discourages most faculty at undergraduate institutions from pursuing research projects because they know that their research can not be as grand as that at large research institutions, because their research will have multiple roles and thus may take longer to complete. Cognizance, during review and funding, of the additional and essential role of research as a teaching tool at the undergraduate level has the potential for institutional change. As is, undergraduate faculty finds it difficult to compete for research support – the effect – fewer students get to learn what science is really about and there is no mechanism by which an institution can improve its programs.

Why is integrating education and research, providing hands-on learning opportunities for students – at all levels and with different career aspirations – in the national interest? The answer is clear and I reiterate: we need a workforce for the future with the kind of skills learned through a rigorous encounter with science and mathematics; we need a citizenry prepared to make decisions about issues with scientific and technological dimensions. Research experiences provide these skills. The corporate leaders on my Board of Trustees regularly describe the kind of people they seek to hire: persons who can ask questions, solve problems and work collaboratively; persons who know how to communicate the results of their work; and persons who know how to use computers and other sophisticated equipment.

Such skills are developed when students have the opportunity to “do science” as scientists do science. More and more, what is happening on campuses across the country is that students are being taught how to ask questions, question evidence, and use computers and other sophisticated instrumentation in seeking answers. Many of the innovative courses now being developed for beginning students provide “research training” opportunities. These courses challenge students to take an active (rather than passive) role in shaping their understanding and to work collaboratively in teams – sharing ideas freely and taking collective responsibility for the results of their work.

We recommend that DUE establish a program of support for undergraduate research which is cognizant of the impact research has on increasing the number of scientifically literate students and potential scientists, as well as the impact that research at undergraduate institutions can have on the quality of the instructional program and faculty of the institution.

The second point I would like to make is that attention must be placed on undergraduate faculty development. A program that truly supports faculty development in teaching/research is needed. I make research and teaching a singular noun because at the undergraduate level, research informs teaching, the two go hand in hand. A program is needed to provide time for faculty to explore bold initiatives to reach more students or teach in a new way. Faculty at two and four-year colleges often teach in an atmosphere where there is not much research occurring. These faculties need to periodically step back into a research-rich environment to replenish research skills and their awareness of current science. Faculties at research universities often are not in an atmosphere, which is conducive for curricular and pedagogical development.

We recommend that a program should support summer or academic year leaves for faculty to work on research or curricular projects that will have an impact on the vitality of the faculty as well as the academic program.

The third issue we must address is that the undergraduate sector is comprised of a great variety of institutions. If we are really attending to the future workforce, we must be conscious of their educational origins, which include two-year colleges, four-year public and private colleges, night schools, and large comprehensive universities. NSF has had a laser approach to a spectral issue. Funding and programs need to reach into where the students are. Scientific literacy is not going to be attained by focusing most support on one, narrow sector of the populace.

The Neal Report targeted a program of comprehensive institutional reform, but DUE has not had the resources to implement such a program. We recommend that such a program be established which would support promising institutions. This program would recognize that real improvement would involve instrumentation, curriculum, and student-faculty research opportunities.

Grinnell has played a leading role in a consortium that has been funded by NSF to reform calculus and a current project to improve chemistry education. We can see that these projects have a tremendous local impact as well as changing the national sense of undergraduate education. It is unfortunate that DUE can only support programs in mathematics and chemistry. We recommend that these highly successful systemic reform efforts be expanded to other science disciplines.

I will conclude with the following observation. We have all talked about the need for improved educational experiences for our children. We have publicly acknowledged that our future leadership, tomorrow's workforce, is today's children. Yet, we do not adequately support the one profession in whose hands these children are. I am talking about teachers from kindergarten through college. NSF, with its dual mission of promoting the human resources as well as the discoveries, has the unique opportunity to make a difference. Through programs which fund teaching and learning science, that barrier between research and teaching dissolves, and the perception of teaching as a lesser endeavor diminishes.

NSF has the power not only approve of innovations in teaching but raise the value of the activity. Such legitimacy will have a direct impact on this future workforce. NSF grants to the undergraduate community set the standards for our work in research, research-training, and education; they provide further incentive to colleges by helping to set parameters for effective planning for curriculum; they leverage critical dollars from other donors, and they enable us to make a significant contribution to the community. To double the budget currently allocated for DUE programs would support our nation's focus on the future workforce. Such an increase [would equate to] doubling a very small fraction (about 3 percent) of NSF budget.

In summary, we have four recommendations:

1) We recommend the creation of program to support research at undergraduate institutions, cognizant of the teaching role research plays at undergraduate institutions.

2) We recommend a faculty development program to support summer or academic-year leaves to support research in curricular development at the undergraduate level.

3) We recommend a program to encourage comprehensive institutional reform.

4) We recommend a program to support systemic educational reform initiatives in the SME&T disciplines.

Pamela A. Ferguson *is currently president and professor of mathematics at Grinnell College. Previously she was associate provost and dean of the Graduate School at the University of Miami where she was responsible for approximately 45 doctoral and 100 masters programs and an undergraduate honors program for 1,600 students. Early in her career she was also an assistant professor of mathematics at Northwestern University. A graduate of Wellesley College, Dr. Ferguson received M.S. and Ph.D. degrees in mathematics from the University of Chicago with National Science Foundation Fellowship support. A member of Phi Beta Kappa, Omicron Delta Kappa, and Sigma Xi, she has received numerous teaching awards. She is a member of the Mathematics and Education Reform Network, the Mathematical Society of America, the American Mathematical Society, and the Association for Women in Mathematics. She served on the Florida Advisory Council for Math, Science, and Computer Education and currently serves on the board of the Iowa Research Council. Her professional activities have included lectures or participation in conferences in the USSR, West Germany, Scotland, England, Hungary, Italy, and many universities in the United States. She is the author of more than 45 articles in leading American and foreign mathematical journals on topics on finite group theory and combinatorics.*

Testimony on the Views of Institutions Toward Undergraduate Education in Science, Mathematics, Engineering, and Technology[1]

Thomas R. Morris

President, Emory & Henry College
Emory, Virginia

I appreciate the opportunity to be here. I am a humble social scientist. I taught political science at the University of Richmond for 21 years before going to Emory & Henry College, where I am in my fourth year as president.

As a political scientist at the University of Richmond, an outstanding small university, I had virtually no contact with natural scientists. They were on the other side of the lake. But one of the things that I found to be very different when I went to Emory & Henry College was the interaction among faculty from different departments. Perhaps it was in part because I had become an administrator and was more aware of the contact. However, I also think it was due in part to the smaller size of the college as measured by faculty size. I moved from an institution with 160 to 175 faculties to one where the faculty totals only 60 to 62. I can report to you that the natural scientists *do* talk with people in the other areas in my institution; there is a great deal of interaction. Because of this interaction, I think there is an opportunity for integrating curricula that you might not have even in small universities, not to mention large universities.

I don't go anywhere without at least saying a word about Emory & Henry College. I believe it is in my contract somewhere. We will be 160 years old next year. The "Emory" was a Methodist bishop, and the "Henry" was Patrick Henry. We consider ourselves to be a premier Appalachian Region, church-related, small liberal arts institution. And for a good number of those 160 years in the Appalachian Region of southwest Virginia and northeastern Tennessee, Emory & Henry have held up the flag of liberal arts education. We have also had a good tradition over the years of turning out science graduates who have gone on to graduate and professional schools and to employment in scientific and technical occupations. There was a period of time when we had a faculty member with strong connections with NASA, and NASA employed many of our graduates. A good number have also ended up in medical professions.

We are associated with the Virginia Foundation of Independent Colleges, one of 15 institutions in that fundraising organization. We are one of 32 institutions in the Appalachian College Association, and we are one of seven institutions across the country that have Bonner Scholar endowments that allow us at Emory & Henry to support 85 students who are of high financial need. In exchange for that financial aid, these scholars perform ten hours of volunteer service in the community each week, as well as participate in a summer program.

I mention those associations to just give you some idea of where we fit into the higher education environment. The University of Richmond, a member of the Virginia Foundation of Independent Colleges, for example, has an endowment of something over $450 million. Most of the institutions in the Appalachian College Association have endowments that are under $8 million.

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[1] This text is an edited version of Dr. Morris' verbal testimony to the EHR Advisory Committee on October 25, 1995.

The size of endowments has implications for the ability of small colleges to improve undergraduate science education. I believe that I am here to speak on behalf of the less well-to-do small liberal arts colleges in the country. I would like to recount a story about a small college president that rings true with me. He was walking in the woods, happened to look down, and saw a shiny object. He pushed the leaves aside and picked it up, and discovered it was a lamp. Being well-educated, he began to rub it, and, sure enough, a genie popped out. Upon learning that the person rubbing the lamp was a college president, the genie said: "I am able to grant you one wish. You may have health, you may have wealth, or you may have wisdom."

The college president reflected and said, "Well, I deal with ideas, work with faculty, and make important personnel decisions, so I certainly should choose wisdom." The genie said, "So be it" and was gone. Endowed with his new wealth of wisdom, the college president sat down on a log to reflect and, a few minutes later, stood up and said: "I should have chosen wealth."

Most of us interested in the health of small liberal arts colleges think that what we need is wealth. At Emory & Henry College, for example, we are getting ready to start another capital fundraising campaign. In my inaugural address, I singled out the arts and the sciences as two areas where I thought we needed to reinvigorate our programs. One of our goals is to raise approximately $8 million to build a new science classroom building. The building we have now is 40 years old, inadequate for the kind of program that we would like to have. In addition, we need at least $1 million to purchase modern laboratory instrumentation for use by our students and faculty, and we also have a campaign goal of accumulating a $3 million endowment to support the updating of technology and instrumentation on an ongoing basis.

At a small institution like Emory & Henry College, we are not certain exactly how we will raise those funds, but that is what capital funds campaigns are all about. We will approach our alumni, particularly those who have gone into the sciences and into the medical professions. We will attempt to do some sight raising with regard to what they might do to contribute to support of the classroom building and the endowments that are necessary to maintain a strong science program.

In other areas, I can easily support [Grinnell College President] Dr. Pamela Ferguson's recommendations. Certainly her testimony earlier today is appropriate for all of the college and university presidents who are talking with you today.

Two major problems for us are limited faculty time and shortage of resources. These are the major obstacles to a successful undergraduate science program, at least at the small college level. In preparation for this session, being a social scientist, one of the things I did was to sit down with the natural scientists at Emory & Henry College and talk about some of the things that were important to them.

Our greatest challenge is to generate the resources to purchase, support, and maintain the instrumentation necessary for our laboratories. We do benefit from a roving repair van that NSF helped us with, which is very useful to the small colleges of the Appalachian College Association, it makes its way around the Appalachian Region and assists the Labs operated by member institutions with needed repairs. That form of collaboration and sharing of resources is very helpful in meeting our instrumentation needs.

With respect to resources, our natural science faculty suggest that colleges with small endowments and more limited resources, however that might be defined, should perhaps be offered less challenging matching requirements and/or longer periods to raise such funds. They also suggest that the application process for programs that NSF wishes to encourage with small amounts of money – up to $10,000, perhaps – be simplified, and they request a simplification of the forms for application and reporting so that they are relatively easy to fill out. Perhaps it was somewhat self-serving on the part of the natural science faculty on our campus, but they suggested that some resources be limited to persons who have not previously been supported by NSF.

We work with the private sector at Emory & Henry. The college has an association with the Eastman Company, not too far from where we are located in southwest Virginia. Recently, Eastman shared with us three important pieces of instrumentation for our Chemistry Department, which were happily received by the members of our Chemistry Department.

Now, with regard to faculty development, I would second all that Dr. Ferguson [president of Grinnell College] said about the importance of that, and particularly the idea of making teaching and research a singular noun. At Emory & Henry, for example, the Physics Department and the head of the Education Department are spending time talking about a conceptual physics course that would be required of all people who are going into teaching. There is a "Teaching of Science" course that is taught for education majors, and there is a great deal of dialogue that goes on between the education faculty and the natural science faculty with regard to what ought to be addressed in that particular course.

The second point I would make is that our greatest contributions to undergraduate science education are the collaborative and integrated teaching innovations that characterize our institutions. As we are all well aware, the excitement of the scientific technique is not generally a part of what goes on in elementary, middle school, and secondary education. Students come to undergraduate institutions like Emory & Henry without having had that experience. Someone has suggested that there is probably more vocabulary in a high school chemistry class than there is in most foreign language courses, to the extent that students have been subjected to simply memorizing and dealing with vocabulary rather than the excitement of the scientific technique at the K-12 level, that makes it more difficult for students and faculty when they advance to the higher education level.

So what I would want to leave with you is the challenge of recognizing that opportunities for creating innovations in undergraduate science teaching are present, particularly at small liberal arts colleges. These colleges do not have the institutional barriers that are more likely to be in place at the large research institutions. One of the things I would encourage the National Science Foundation to do is, support those faculty who are willing to work with innovative, integrative, and collaborative teaching possibilities; with regard to undergraduate science education, then follow up on an ongoing basis, evaluate the effectiveness of new approaches, and find ways to report methods and findings to the larger academic community, through articles, lectures, and workshops.

I would argue that at this time in our history, it is probably as important to be putting resources into how students learn science as perhaps it is into the more traditional type of science research that is going on, and the laboratories in the form of small liberal arts colleges are there to make that possible.

Thomas R. Morris *assumed office on July 1, 1992, as the 19th president of Emory & Henry College. A distinguished Constitutional scholar and political scientist, he brought to the college 21 years of higher education experience at the University of Richmond. Dr. Morris also is well known on a state and national level as an astute political commentator and writer. A native of Galax, Virginia, Dr. Morris earned a bachelor's degree in government at Virginia Military Institute, studied at Princeton University, and then completed Masters and Doctoral degrees in government at the University of Virginia. He received fellowships for additional advanced study including a year as a Liberal Arts Fellow at the Harvard Law School and a year as a fellow of the National Endowment for the Humanities at the University of Wisconsin-Madison. He has also served as a political analyst for television, radio, and print media over the past fifteen years.*

NSF Review of Enhancing Science, Mathematics, Engineering, and Technology Education

Bruce H. Leslie

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Thank you for the opportunity to share my thoughts and those of my colleagues regarding science, math, engineering, and technology education (SME&T). The invitation comes at a time when our nation appears to be redefining itself in the post-Cold War era, but also at a time when new extraordinary forces are rapidly exerting their influence upon the void created by the end of superpower military competition, replacing it with complex economic competition. Science and technology are, many of us contend, more important in this new era, than ever before.

There are a number of obvious problems with the current state of science and technology. Such problems are cyclical and reflect the need for adjustments in our response to shifts in the environment. Many of us are the product of such a response by the nation to *Sputnik*, which created "accelerated" federal initiatives in our math and science education programs to correct newly perceived deficiencies. Perhaps a similar response is called for today, despite the differences in the environment of the late 1990s vis-à-vis the late 1950s. Just as opportunities presented themselves 30 years ago, today's opportunities should be capitalized upon to positively affect our national competitive and social objectives. In one sense, NSF has already initiated such a response by greatly expanding its interest in, and support of, the nation's community colleges. The other half of our undergraduate students now have the opportunity to be impacted. My colleagues and I are most grateful.

Rather than summarize perceived problems, for they are explored more effectively in numerous other venues, and are inferred in my comments, my intent here is to suggest the possibilities inherent in today's environment. Such opportunities exhibit themselves in the following themes:

1. The growing national agenda to address the needs of youngsters so they are adequately prepared for success in school. Programs such as *Head Start*, Eisenhower grants and *Success by Six* exemplify this trend.

2. Recognition that youthful excitement and discovery, brought naturally into the world, but often suppressed early in childhood, must be enhanced and nurtured, especially in a world where "life-long learning is the only job."

3. Capitalizing upon the *Nation at Risk* movement that has been, for the past decade, gradually changing our thinking about how best to foster learning.

4. The infusion of technology, especially computers, into our schools, homes and day-to-day world.

5. The growing interest by the business community to ensure a technologically sophisticated populace both to provide the needed workforce and a consumer capable

of using, and thus interested in buying, the increasingly complex products being developed. Our very economy, and the success of business, depends upon an educated citizenry. As the world becomes better educated, this will become a greater competitive challenge and opportunity for business.

6. The internationalization of the economy, a growing worldwide competitive environment, and increasingly sophisticated defense requirements created by a changing world, suggest that the nation's continued strength is dependent upon maintaining a technological edge across all sectors of public and private systems.

These opportunities describe an agenda for improvements in the SME&T aspects of our educational system. Three specific recommendations should drive NSF's considerations:

1. We know what works. NSF should help the nation's educators implement the proven principles. Although continued exploration to improve learning is important, fewer resources require us to widely apply what we already know.

2. SME&T must be infused with broader skills, which today are required in the workplace: customer orientation, quality, teamwork, problem solving and leadership.

3. Colleges must apply affective domain strategies, especially for second and third quartile students who can and must succeed. The traditional emphasis on the discipline itself excludes the larger proportion of our citizens.

In order to profit from the opportunities before us, four themes are recommended:

1. Improvements must begin with the faculty. Each of us has personally experienced or observed the positive affect a teacher can have on a student by inviting her/him into a course or discipline. Conversely, teachers too often discourage a student from pursuing a field or career, especially in math or science, by ignoring or redirecting them to "easier" studies. Faculty who must democratize the process will recruit the future generation of scientists and technicians. To achieve this, faculty must:

    - Receive better preparation in graduate school to become recruiters and nurturers of the next generation of scientists by learning how to excite students into entering these fields. Faculty should become skilled at positive reinforcement and the means by which students can be encouraged to pursue SME&T. Students of color and women must receive strong encouragement to enter these fields. So called "average" students must be nurtured since almost every future employee must be sophisticated in math and technology. Such programs as the NAACP's *Act-So*, science fairs, and kids colleges create enthusiasm that attract potential scientists of any age.

    - Diminish the "elitism" of SME&T so that fewer individuals will be intimidated by study in these fields and more will choose to enter the professions, especially at the technician level where job data suggests strong future growth. Faculty is especially important in the decisions many students make to pursue or not to pursue such studies.

- Be skilled as learning facilitators, not lecturers, and curriculum designers, not just subject matter experts, with an emphasis on application, learning outcomes, measurements, and subject integration among relevant disciplines. All current faculty must be similarly retrained.

- Be student centered rather than faculty centered. Learn how to nurture and/or reinvigorate students' excitement and positive self -concept about learning SME&T.

- Be steeped in the use of such techniques as classroom research, learner-centered instruction and team study.

- Infuse curricula design and instructional tools with the interests of the secondary schools and employers. The transition from school to work should be "seamless."

- Become sophisticated in organizational operations, to better structure disciplines within the college or university in ways, which facilitate realization of educational ends. The barriers between subjects and disciplines must be removed so that the integration of knowledge is modeled for students.

- Be competent in the use of computers, not only in the demands of the discipline, but in their use as instructional and class management tools as well.

- Commit to life long learning in order to remain current in the discipline *and* in the classroom.

- Be open to business sector professionals who often have more knowledge of learning theory and curricular design than academics. ASTD and other professional associations produce and distribute the most current research materials in learning theory. Such companies as Motorola and Nvnex are demanding outcome accountabilities from their educational venders and are teaching college faculty how to adopt new learning theories. Educators must become open to such expertise, rather than reject it because it's from outside the academy.

- Become knowledgeable about the national skills standards program and, with employer's active involvement, integrate results into the curricula.

- Make mathematics a more accessible and less threatening language to American students. It should become more applicable and less theoretical so that students understand its use and importance.

2. Post-secondary institutions are in the position to provide leadership. They must:

- Invest in faculty development as described above.

- Ensure faculty have the technology available and working, and the means to use it.

- Structure the college, organizationally and within facilities, so that curricula and disciplines are integrated. The academic department, both structurally and geographically within the college, reinforces isolation of disciplines and faculty. New structures must be explored which create an academic version of a business environment where information flow, organizational learning and technology interface. This is the developing model of the post industrial information age. Education should adjust itself, as it did in the beginnings of this century, to reinforce demands on both its management and "production."

- Provide the means to define, measure, and continuously improve learning ends. This will distinguish the college as accountable at both the management and academic levels, and build trust with employers, sponsors and, most importantly, students and their sponsors.

- Initiate tech-prep, school to work, co-op, apprenticeship and other such models to create the relationship between college, business and student, that provide the practical work skills necessary.

- Ensure the curriculum emphasizes SME&T within a framework of the humanities.

- Partner with business to explore and, where appropriate, implement the results of the national skills standards program.

- Reward faculty for applied teaching rather than research, for being risk takers, for being change agents rather than the defenders of the proud traditions of academia, for forming alliances with business and community.

3. Because of the multiple level of employers' interests in a technologically sophisticated society they should:

- Become invested in the development of our nation's students. The German approach is not the only possible model, but its integration of business into the nation's educational system provides many benefits to both. An "apprenticeship" emphasizing science, math, engineering and technology already exists through co-op programs and is being expanded through tech-prep initiatives. Business should greatly expand opportunities by utilizing such models as the Ford Asset program, which prepares automotive technicians through community colleges and co-ops with the sponsoring dealers. The faculty receives annual training and the college new technologies. But must important, the students are employed by the dealer upon graduation, and ready for a successful technological future.

- Assist secondary and post-secondary institutions by contracting with faculty. Such arrangements increase their knowledge and enhance the preparation of students. Many of the skills today's employers require, including in SME&T, such as teamwork, problem solving, leadership, quality, customer orientation, and organizational understanding (see Tony Carnavale, Workplace Basics: Skills Employers Want, *The American Society for Training and Development,* 1990), are most effectively taught through work place application.

- Partner with education to ensure the technology is adequate and remains current. The company benefits by ensuring new employees are adequately prepared and existing employees are continuously retrained without down time at the business. Ford ensures this through its *Asset* program; but smaller, local businesses reap similar benefits through modest investments. Education's ability to remain current in technology will depend to a large extent on business investment in such alliances.

- Partner with education to implement the results of the national skills standards program. Together, this effort, which is similarly occurring in many other nations, may provide important benefits to both business competitiveness and development. Jamie Houghton, president of Corning, is the chair of the board, indicating the level of business interest in the 22 projects underway.

4. The National Science Foundation and other federal programs can support the necessary changes by:

   - Establishing a national agenda, which integrates employers, educators, and students into a “seamless” system of learning from elementary through college and life-long education.

   - Nurturing the public's awareness of, and interest in, SME&T by clearly describing the need and defining understandable national objectives. Then funding programs which, on a long-term basis, will reinforce the objectives and attain desired ends.

   - Creating long range programs rather than short-term projects. This will also benefit educational efforts by reducing uncertainty of funding, allowing projects adequate time and resources to achieve high levels of impact.

   - Replicating the already excellent work achieved at less cost than developing anew. Initiate a mechanism to make the best programs available for transfer and to encourage their implementation.

- Assisting smaller institutions which make up the largest number of individual organizations, but lack the resources for professional grant writing and are, thus, absent from the benefits of grant funds, to develop the means to be included.
- Emphasizing development of faculty, including counselors and advisors, to reinforce the skills required by future and current educators, to prepare a citizenry sophisticated in SME&T. Change often happens only when money is made available, where there is a means to pursue new directions.
- Support organizational model development and implementation, which will foster the integration of knowledge and learning.
- Broaden the emphasis of science and technology education away from only those whose goal is a career in science and math, to all students. Eliminate the perception of elitism by opening SME&T to all students.

In summary, an environment exists, which if effectively mustered, holds the prospect of much opportunity for SME&T development and enhancement. The short-term prospect may appear to be negatively affected by current budget balancing. On the other hand, many forces favor a national agenda by which government, business and education collectively strengthen the means by which teaching and learning, curricula innovations, technology, organization and supplemental academic programs integrate to prepare a more scientifically sophisticated citizenry.

Today and forever, we must teach a "different" science than in the past. Knowledge is expanding exponentially and the classroom by itself can no longer remain the single place for learning. Technology, including multimedia, the Internet, and simulations hold much promise to augment the basics covered in class. But new approaches such as learner centered and team based programs, co-ops and internships all must be used collectively to provide students adequate skills to contribute to their society and employers.

By focusing on faculty development, the creation of teachers as nurturers and facilitators; the integration of learning ends into the instructional process; implementation of organizational models which enhance the achievement of academic outcomes; partnerships between business, students, faculty and colleges which fulfill the academic vision; and, with NSF and other federal programs providing national leadership, long range direction and funding and a broader base of SME&T education. This nation can maintain its competitive edge while providing a better standard of living and society for its citizens.

***Bruce Leslie** has been a Director of the American Association of Community Colleges, chairing the Association's Public Relations Commission. He is currently Chancellor of the Community-Technical Colleges of Connecticut. He is also a Director and treasurer of the American Society of Training and Development, having chaired its Technical and Skills Training Committee, served on its National Issues Committee, and served as a member of the Editorial Board of ASTD's Technical Skills Training Journal. Dr. Leslie has served on the boards of the Urban League, Salvation Army, Private Industry Council and similar organizations in Syracuse, Chicago and Seattle. He has received the Harriet Tubman award from the Urban League, CEO Recognition Award from the American Association of Community College Trustees, Distinguished Alumni Award from the University of Texas, The Paul Dunbar Community Service Award, and Outstanding Community Service Award for Excellence in Education from Phi Beta Sigma.*

National Science Foundation Review of Undergraduate Education Institutional Perspectives of College and University Leaders

Gwendolyn W. Stephenson

Chancellor, St. Louis Community College
St. Louis, Missouri

Thank you for this opportunity to speak before the National Science Foundation's [EHR Advisory Committee for the Undergraduate Review]. I am sharing my concerns and recommendations with you today as chancellor of St. Louis Community College, as a former teacher, and as a member of a very strong national network of community college leaders. My remarks are concerned primarily with instructional programs – the fundamental exchange of information between teacher and student that is at the heart of both personal developments for the student and economic development for our nation.

Community colleges pride themselves on the quality of their teaching and instructional delivery systems. As open door institutions, we must accommodate a diversity of learning styles and many levels of ability. Community colleges occupy a unique place in higher education. We are midway in the public education continuum that extends from pre-school to post-graduate programs and lifelong learning opportunities. We are in a position to understand the problems and potential of education at all levels and cooperate in programs to improve the performance of students of all ages.

Our position is pivotal as we consider:

- how to improve literacy in science and technology of students majoring in other disciplines;
- how to strengthen the knowledge base of those earning associate's and baccalaureate degrees in science, mathematics, engineering and technology; and
- how to change our institutional policies and practices to aid undergraduate education in science, mathematics, engineering and technology.

Certainly, we must continually support two overall goals: improving student achievement, and improving instruction through the development of curricula materials, faculty preparation, and instructional activities.

About one-half of all the nation's first-time freshmen are enrolled in community colleges, and community college students make up the largest sector of higher education in the U.S. – 37 percent. About 47 percent of all minorities in college attend community colleges, as well as more than half of higher education students with disabilities.

Many of these students come to us with academic deficiencies in mathematics, and community colleges offer extensive programs in developmental studies. In many States including Missouri, legislators and educational agencies have mandated that baccalaureate institutions scale down or eliminate their remedial and developmental programs, thus leaving this complex task almost totally to community colleges. I have come across a significant number of legislators who resent what they consider double payments to prepare students for college-level work in mathematics. They feel that their support of secondary-level programs should be sufficient.

We know better. In St. Louis (and we are not much different from most large urban districts) nearly 25 percent of our students who enroll for college credit – or more than 6,800 – are taking at least one developmental course. This is up from 19 percent five years ago. These numbers include those students who also exhibit deficiencies in language and the ability to read, think critically, problem-solve, observe and respond Our faculty would argue that language deficiencies contribute significantly to mathematics and science deficiencies. We also are seeing a widening gap between the upper one-third and the lower one-third of high school classes.

The problem of under-prepared students clouds our vision of full participation in the global economy and of competitive economic development at home. In addition, our academically able students must master increasingly complex concepts and applications as the SME&T curricula evolve to match technological advancements. We are deeply concerned about the widening gap between the expectations of business and industry and the inability of significant segments of the work force to meet these expectations or even to function as informed consumers of technology.

But under-prepared students – as well as the sheer numbers of able students who attend community colleges – also provide educators the challenging opportunity to experiment, to take risks, to find innovative ways to teach mathematics, science, engineering and technology. If we can be successful with our students, we can influence and improve teaching methods at the elementary-secondary level, at the undergraduate level, and in industrial training.

I would like to briefly share with you a few examples of programs at St. Louis Community College, which are moving us forward in this critical area. Many community colleges across the country currently offer similar programs.

- Our *Minority Engineering Scholarship* program is sponsored in conjunction with Emerson Electric Company and the University of Missouri-Rolla. Recipients take the first two years of their engineering studies at the college, then transfer to UM-Rolla to complete the remaining two years. Since the program started in 1988 80 students have enrolled, seven have graduated from the university and 22 are currently in the program's pipeline. The completion rate compares favorably with a national retention rate of 35 percent. Ninety percent of our regular engineering transfers graduate from UM-Rolla, and we find they do as well or better academically than those students who start as freshmen at the university. The program has been so successful that we are exploring a similar tripartite relationship with the St. Louis College of Pharmacy and Monsanto Company.

- We are entering our fourth year of leading development of the *St. Louis Area Tech Prep Consortium.* Sixteen local school districts are members of this initiative, representing more than two-thirds of the public high school-age population in the area. Our faculty members work with teachers at the junior and senior levels in local high schools to blend the curricula and ensure smooth articulation.

- The college has participated in a NSF-funded program directed at middle-school students. Partners in the project included the University of Missouri-St. Louis and Harris Stowe State College. In addition, our mathematics faculty members have been called upon to teach at all levels because of their skills and the measurable results that they have achieved.

I am sure you have noticed a strong, common thread running through these sample programs – and that thread is partnerships and collaborative efforts. I am convinced that the only way our educational systems and our nation can advance in SME&T education is to do so in tandem with other educational institutions and with business and industry. The material is too complex, the required delivery systems too costly, the technological advancements too rapid, and the economic imperatives too critical for educational systems to meet the challenges independently. Such laudable programs as Tech Prep and School to Work are only the beginning of collaborative efforts we must create to prepare our students for the demands of the next century.

When the National Science Foundation is asked to support programs in curricula development, science-mathematics literacy, faculty development, work force preparation, and laboratory instrumentation, it should do so within the context of institutional collaboration. As we all know, funding is a powerful motivation for change, and *NSF* should insist that institutions demonstrate their concern for articulation, cooperation, logical course sequencing, and resource sharing in their proposals for support. The concept of teamwork in problem solving, so critical in the work force, should be reinforced at every level in the educational process.

Community colleges are most grateful that the National Science Foundation has increased its support over the last five years from about $1 million to more than $30 million. The renewed NSF emphasis on teaching – rather than just research – and work force education has been received with much enthusiasm by community colleges who are on the front line in the battle for mathematical and scientific literacy and career preparation. The Instrumentation and Laboratory Improvement program has helped update science labs in ways that would not have been possible before the program; and other funding has helped update our curricula through acquisition of new computers, CD-ROM, and video disks.

Future NSF support should focus on the following areas:

- *Increased availability of sophisticated instrumentation in laboratory work.* There is a world of difference for students between, for example, learning how to interpret an NMR in a textbook and actually taking an unknown sample, running the actual NMR spectrum and interpreting the information to arrive at the identity of the compound. Students become very enthusiastic when they are involved in hands-on experiments that mirror what a scientist might do. Similarly, the increased use of CD-ROM and videodisks helps students visualize the concepts being studied. Science is observational, and the use of more video techniques helps students – particularly in the field of chemistry – see what cannot be seen. Computer use should be interactive and kinetic, not limited to static data acquisition and display.

- *Enhanced faculty development.* Such programs as national exchanges among colleges and business and industry would reinforce workforce expectations. Workshops on technological advancements and curricula development would encourage faculty to adapt to change and incorporate more innovative teaching methodologies.

- *Continuous integration of SME&T instruction among elementary-secondary, community colleges, and university systems.* In every community, these three levels should be linked to produce a logical sequence of instruction and an appropriate knowledge base for all students, no matter what their major course of study or career plans. Particularly in the public sector, our state legislators, educational agencies, and taxpayers are beginning to demand no less.

- *Expansion of curriculum reform*. The calculus reform movement and the development of standards, such as NCTM, are excellent steps in this continuous process. More emphasis (and funding) should be focused on interdisciplinary curricula, improved textbooks, and assessment methods.

Once again, thank you for the opportunity to outline concerns and recommendations today. Community Colleges look forward to a continued productive and mutually beneficial relationship with the National Science Foundation.

Gwendolyn W. Stephenson *was appointed chancellor of St. Louis Community College in February 1992. She leads an institution that includes three campuses – Florissant Valley, Forest Park, and Meramec – and four education canters; serves more than 120,000 credit and non-credit students annually; employs more than 3,400 faculty and staff; and is supported by a budget of more than $100 million. From 1988 until her appointment as chancellor, Dr. Stephenson served as president of College's Meramec campus. She joined the College in 1980 as dean of student services at the Forest Park campus. She served as the College's vice chancellor for planning and academic affairs from 1982 to 1986, and as vice chancellor for educational development from 1986 to 1988. Before joining St. Louis Community College, Stephenson was employed by Washington University in St. Louis for seven years. She also has worked for Southern Illinois University-Edwardsville, the Missouri Department of Education, and St. Louis Public Schools. Dr. Stephenson earned a doctorate in education with a minor in research methodology in 1975 from St. Louis University and a management certificate in 1987 from Harvard University. She received a master's degree in counselor education in 1968 from St. Louis University and a bachelor's degree in education in 1965 from Harris Teachers College. She is a licensed psychologist in Missouri. Dr. Stephenson serves on numerous state, regional and national educational advisory groups and on the boards of directors of local organizations including St. Louis Science Center, St. Louis Children's Hospital, St. Louis College of Pharmacy, and the Urban League of Metropolitan St. Louis. She also serves on the board of directors of the American Council on Education and the Advisory Committee for the National Science Foundation's Division of Undergraduate Education.*

Testimony on the Views of Institutions on Undergraduate Education in Science, Mathematics, Engineering, and Technology[2]

David R. Pierce

President, American Association of Community Colleges
Washington, District of Columbia

My role here this morning is to be here in support of two very fine representatives of community colleges [Dr. Bruce Leslie, President of Onondaga Community College of New York, and Dr. Gwendolyn Stephenson, Chancellor of St. Louis Community College of Missouri.] These two outstanding leaders have both served on our Association's Board and have both been in leadership positions while on the Board.

I do, however, have a couple of observations to make. First, let me congratulate Dr. Melvin George, Dr. Luther Williams, and Dr. Robert Watson for their fine leadership in sponsoring these hearings. There is a tremendous change going on in our society, and much of it is being driven by science and technology developments. The important question is: how can the National Science Foundation engage its many resources and programs into helping our country and its citizens live in this world of rapid change?

I read an article on productivity two weeks ago in *Business Week*. The article stated that we now have 62 PCs for every 100 people; we are almost at the point where there is one PC out there per person. The country closest to us by that measure is Japan, with only 17 PCs per 100 people. This fact can be viewed as a statement of the impact that science, mathematics, engineering, and technology are having on our society. Consequently, these are very important hearings that you are holding and we are pleased that you have invited us to present testimony. We know you will benefit from the perspectives of these two presenters.

One other point I'd like to make is that Bruce Leslie mentioned the document *Crossroads in Mathematics: Standards for Introductory College Mathematics Before Calculus*. This was funded in substantial part by the National Science Foundation. This process that produced this document was very significant, because the National Science Foundation took leadership to engage the community college sector in a leadership capacity relative to higher education. These standards are intended to be – and in fact are they have just been out for a month – the standards for mathematics below calculus in undergraduate education, for both community colleges and universities. The community college sector considers this document as a statement from the National Science Foundation of the importance of engaging community colleges and universities together in common cause.

In closing, let me remind you that community colleges are strongly community-based. They are engaged with their communities to help thrive in this strong technology, science, mathematics, and engineering-based society that we live in. Community colleges have an important role to play.

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[2] This text is an edited version of Dr. Pierce's verbal testimony to the EHR Advisory Committee on October 25, 1995.

David Pierce *has extensive community college experience at the local, state, and national levels. During his career he has served as a community college instructor, department chair, academic dean, president, chancellor, and state director. In addition he holds an associate of arts degree from Fullerton College in California. Including his time as a student, David Pierce's experience with community colleges exceeds 35 years. His professional involvement includes service on the Board of the American Association of Community Colleges, the AACC Futures Commission, and the Joint Commission on Federal Relations for AACC and the Association of Community College Trustees; and he serves on numerous boards and councils including the Phi Theta Kappa Board, the AAWCC Leaders Foundation Board, and the Advisory Board for the Harvard Institute for the Management of Lifelong Education.*

Institutional Perspectives of College and University Leaders

Frederick S. Humphries

President, Florida A&M University
Tallahassee, Florida

Thank you Mr. Chairman, for this opportunity to share my thoughts with you on some of the most critical issues impacting undergraduate education in Science, Engineering, Mathematics and Technology. My comments, while broad in concept, speak to the rapidly changing demographic trends that are reflected in the increasing presence of members of minority groups in primary and secondary school systems today.

"This country must sustain world leadership in science, mathematics, and engineering if we are to meet the challenges of today ... and of tomorrow." These are the words of President William J. Clinton that served as the preamble in the report of the Forum on Science in the National Interest, held in January 1994. This report also states that "... science and mathematics education must provide our children with the knowledge and skills they need to prepare for the high-technology jobs of the future, to become leaders in scientific research, and to exercise the responsibilities of citizenship in the twenty-first century."

One of the major roles of the National Science Foundation is that of ensuring that the country's educational system provides to this country's citizenry a level of training that will produce the technological workforce that will be required in the twenty-first century. This system must translate new information rapidly and efficiently to students in the classroom, capitalize on new technologies that will enhance learning abilities, and afford to every student an opportunity to effective utilization of his/her creative abilities. As is implied in the words of President Clinton, public literacy in science and technology is no longer an option; it has become a national imperative.

Having made these opening observations Mr. Chairman, I must express concern that demise of Russia as a major world power has lessened this country's resolve to maintain a strong and vibrant science and engineering education enterprise at the undergraduate level that will provide sufficient training to all of its citizenry. We must remember that the strong system of secondary and higher education of the sixties and seventies produced the American Nobel Laureates of the nineties. This country has developed a cadre of science and engineering research universities that are unparalleled in their ability to provide state-of-the-art graduate education. Data shows however, that the majority of American entrants into this graduate education system are bachelor degree recipients from the smaller liberal arts colleges and comprehensive universities. Accordingly, I would argue that we must continue to maintain a strong undergraduate science and engineering training program in these institutions so as to maintain this country's scientific preeminence.

In the same vein, our education system must ensure ample opportunities for training for the increased number of minorities in SME&T fields. The stature of America into the twenty-first century will be defined by the contributions of all its citizens. We must sustain the educational intervention programs that enhance the preparation of inner city and rural youths and insure that every person has an adequate opportunity to serve as a contributing citizen.

The National Science Foundation has supported the development of partnerships of the multiple stakeholders to impact and enhance the educational continuum. These coalitions have provided manpower and resources that reinforce areas in which we, in academia, require assistance. It also serves to provide students real life experiences that make classroom learning more meaningful.

The technological revolution has bypassed the inner cities and is deficient in equalizing opportunities provided to this segment of the population with the scope of their desires. This failure can be attributed to society as a whole rather than the individual educational consumer.

Teachers who do not have access to technological equipment cannot teach the technology skills required of a competitive society in the next century. Curriculum revision cannot take place if adequate resources are not available. The technological age is a cost driven age.

Several years ago the National Science Foundation budget was about \$1.7 billion. President Bush promised that he would double NSF budget to approximately \$3.5 billion. The member institutions of the American Association of State Colleges and Universities through its Science and Technology Committee recommended that as the National Science Foundation budget increased, the increase would place a significant emphasis on education – two-thirds research and one-third education. This would have increased the education budget to something on the order of \$1.2 billion if our recommendation had been followed.

Education today is more expensive than it has ever been but it will cost more to ignore this inequality than it would to provide the proper resources for science education at the undergraduate level.

The National Goals, which were proposed in the early 1990s, represent a framework for addressing the educational needs of all citizens.

As this nation forges ahead to become first in the world in science, mathematics, engineering and technology, the needs of minorities must be addressed. The stature America will hold in the 21st century will be defined by the contributions of all of its citizens. Education will play a major role if this mission is to be accomplished. Educational interventions that are inclusive of all citizens, that are sustained and substantial, are the only means for success.

The growing diversity of industry/education partnerships, which are coming together, enhances education. These coalitions provide manpower and resources that shore up areas in which we, in academia, have lost support. It also serves as a means of providing a needed continuum in education.

In a similar view of cooperation, collaborations are beginning to emerge between our two-year anal four-year institutions. Since the two-year institutions serve a large number of minority students, the linkages, which are developing between the institutions of higher learning, appear to be facilitating student access to the upper-division level. More effort needs to be made in this regard.

There is a crisis in graduate education. The intractable movement of African Americans into the Ph.D. ranks, particularly in mathematics, science, and engineering, is unacceptable. This nation cannot seem to surpass the progress made in the 1970s for Ph.D.s in engineering, or even secure double digits for Ph.D.s in mathematics. Barely 19 or 20 Ph.D.s are being awarded annually. It is an embarrassment to this nation that we cannot do any better than that in the production of African Americans in the Ph.D. arena.

A second significant point pertaining to graduate education is the continuing erosion of Ph.D.s in science, mathematics, and engineering given to native-born Americans. Every day that we live, more and more Ph.D.s are awarded in mathematics, science, and engineering to a greater number of international students and a lesser number to native-born Americans. This nation is failing to train its best people. This should be of serious concern to everybody who is concerned about the production and the development of the human resource in this Nation.

The federal government has recognized the value of early and sustained intervention in preparing minority youth for careers in the science, mathematics, engineering and technology areas. The last decade has seen support for the efforts being made at the university level. The level of support must be projected on a long-range basis granted that the programs demonstrate success. The system-wide approach to reform sparked by the National Science Foundation is taking hold in the various states, which are receiving support. There is more evidence of partnership and collaboration than at any time in our history. These partnerships and collaborations have generated the feeling that, it will take the efforts of an entire nation to educate our youth.

In the K-12 system there is a lack of first-rate science and mathematics education providers to the rural and urban sectors of our society. Most of the well-trained science and mathematics teachers are not teaching in the inner cities and rural areas of America. We have a modest level of success with mathematics and science teachers in the suburban areas. That is where the best education in science and mathematics is happening.

In rural and inner cities, many of the schools lack mathematics and science infrastructure. This results in inadequate mathematics and science laboratories. When many of the students graduate from these school systems, they are termed “underprepared” and need remediation in mathematics and science to be competitive in any reasonably good university or college in our Nation.

We have all kinds of circumstances where we reward and pay homage to distinction and achievement in research. There are a tremendous number of opportunities for the people who make contributions to the advancement of knowledge through research to be acknowledged for their significant and dedicated hard work. We need an organization that focuses on and requires annual professional meetings dealing with this whole issue of making scientists, engineers, and mathematicians. What works effectively in the curriculum? What is the curriculum restructuring mechanism?

The National Science Foundation needs to use its tremendous influence to make way within the National Academy of Science and Engineering so that the great teachers of science and mathematics can be afforded the privilege to belong to the academy in an educational capacity and not in a research capacity.

There are teachers who develop good scientists, mathematicians, and engineers; teachers who are inventive in finding ways of captivating the interest of young people to go into those fields; and master teachers who can solidify that interest by inspiring a student to become a Nobel Laureate. *Build a mechanism, which reinforces the notion that it is worthwhile to pay attention to these very important activities in our society.*

Programs developed in the Education and Human Resources Directorate of the National Science Foundation are tremendous and excellent starts, but they are not the end in terms of what is needed to be done to continue this role of increasing the numbers, particularly of minorities, and increasing the numbers generally of our society in mathematics, science, and engineering.

Given the political climate of the past several years, it is evident that the academic arena cannot accomplish this mission on its own. We must have the full commitment of partners who believe in a system of fair and equal opportunity for all. One of my major concerns is the fact that support for public colleges is becoming more dependent on revenues from tuition and fees owing to the decrease in funding from State and Federal sources. This situation has even greater impact on the number of minorities progressing through the system and receiving baccalaureate degrees in four to six years. Increasingly, minorities enrolled in college are required to carry reduced course loads or even delay college owing to the combination of limited financial aid, rising tuition and the limitation of course availability. Budget compression is forcing institutions to increase class size in order to maintain existing levels of enrollment.

If America is serious in its desire to maintain its lead in the world in science and technology, then America must be committed to providing the necessary resources to see that adequate SME&T training is available to all students in secondary and post-secondary education.

Listed below are my recommendations of a realistic approach to a comprehensive action-oriented revolution of our educational system:

- Promote the development of new curricula emphasizing virtual reality and simulation training in the teaching of science, mathematics, engineering, and technology subject areas at the undergraduate levels.
- Promote the development of State/Federal partnerships to fund the replacement of aging facilities and equipment utilized in teaching science, mathematics, engineering and technology subject areas.
- Increase the level of science, mathematics, engineering and technology funding designed to attract students from the inner city and rural areas.
- Promote collaborative efforts among faculty that will facilitate a multidisciplinary approach to the education of all students regardless of major.
- Promote the dissemination and utilization of science, mathematics, engineering and technology curricula that have proven successful.

- Establish an organization to focus on the professional development of scientists, engineers, and mathematicians.
- Encourage the National Academy of Science and Engineering to expand membership requirements to include science and mathematics in an educational capacity.
- Fund and promote the utilization of distance learning facilities to infuse science, mathematics, engineering and technology instruction into secondary and post-secondary curricula.
- Fund and promote partnerships between higher education and industry that will ensure relevant laboratory experiences for the next generation of the science, mathematics, engineering and technology workforce.
- Ensure the education of a sufficiently diverse science, mathematics, engineering, and technology workforce so as to afford each citizen an opportunity to contribute to the country's well being.
- Forge at both the state and national levels, communities of stakeholders – students, parents, faculty, administrators, scientific sources, accessible bodies, employers and local, state and national leaders – who demonstrate their support for education.
- Create an environment where faculty can effectively integrate their research and teaching at the undergraduate level.
- Provide a level of support, which will enable the K-12 system to effectively administer programs, which demonstrate and enhance comprehension of scientific and technological subjects.
- Introduce prospective teachers to the classroom setting early in their preparation and continue this exposure while developing their proficiency in science, mathematics, engineering, and technology.
- Promote the development of University-Community College articulation agreements that provide services to promote scientific interest and scientific literacy before students complete their associate degree programs.

Recently there has been a high level of concern about the quality of the products of our undergraduate institutions and questions regarding their preparation for diverse post-matriculation endeavors. The enhancement programs, which are emerging with Federal and State support, have demonstrated that a comprehensive and holistic approach to learning will produce students who are up to the challenges of post-graduate education.

I strongly endorse continuation of the Following National Science Foundation Initiatives:

- Instrumentation and Laboratory Improvement;
- Course and Curriculum Development;
- Undergraduate Faculty Enhancement;
- National Science Foundation Collaboratives for Excellence in Teacher Preparation;
- the Alliance for Minority Participation in Science, Engineering, and Mathematics;

- the Systemic Statewide Initiatives Programs; and
- the Advanced Technological Education program.

Furthermore, I strongly support the continuation of undergraduate programs sponsored by the National Institutes of Health, Minority Access to Undergraduate Careers Research Program, Minority Biomedical Research Support Program – and the office of Naval Research such as BIONR. All these programs have played a vital role in increasing the pool of minority scientists and engineers in our country.

I urge you to make the tough decisions and redirect funding so that all undergraduate students would have access to state-of-the-art equipment, modern facilities and innovative curricula anchored by inspiring and well prepared professors. We must rise to the challenge if we are to meet the technological demands of leadership in the 21st century.

*When **Frederick S. Humphries** was appointed President of Florida A&M University in 1985, he brought new tools and ideas designed to dramatically impact the national perception of Historically Black Colleges and Universities. He set as a major goal early in his administration to challenge Harvard University in the race for National Achievement Scholars, the most academically talented black students in the country. He accomplished his goal in 1992-93 and again in 1994-95 when FAMU led the nation in the recruitment of National Achievement Scholars. He serves on numerous boards and committees including the White House Advisory Committee on Historically Black Colleges and Universities, and as a member of the Board of Directors for the Wal-Mart Corporation. His honors include the University of Pittsburgh's Bicentennial Medal of Distinction and the 1990 Thurgood Marshall Educational Achievement Award. He received his bachelor's degree in chemistry from Florida A&M University and the Ph.D. degree in physical chemistry from the University of Pittsburgh.*

Testimony Before the Undergraduate Review Subcommittee of the National Science Foundation

William E. Kirwan

President, The University of Maryland
College Park, Maryland

Mr. Chairman, I am pleased to be able to appear before the committee created by the National Science Foundation to review undergraduate education the areas of science, mathematics, engineering, and technology (SME&T). I hope that my comments will be useful to you as you begin this important undertaking.

You have identified a number of broad issues relating to science and technology education in our nation's colleges and universities. My remarks will focus on two of your major concerns: improving the quality of the undergraduate curricula in SME&T areas, and identifying changes in institutional policies and practices that might contribute to the desired changes. I would be happy to address the remaining issues, if time permits, in response to the committee's questions.

Strengthening Curricula in SME&T Fields

Certainly one key to improving instruction in areas of science and technology will be affording our students greater access to powerful and easy-to-use computers for data analysis, simulation, and instrument interfacing. The networking of computers has opened up the processes of information gathering, analysis, and the dissemination of knowledge, and the effects are already visible in many of our classrooms. Computer linkages with federal agencies and private industry now offer invaluable opportunities for our undergraduate engineering and science students to use state-of-the-art design models. In the near future we can expect to see a dramatic increase in the number and variety of electronic texts being made available for use in undergraduate instruction. In our electronic classrooms at College Park we have observed first-hand the tremendous potential of computers to enhance learning, and there is every reason to think we are just at the beginning of this era.

There is also now widespread acceptance of the proposition that, in science areas as in other disciplines, students learn best when they work within problem-focuses formats. Where students can take an active or 'constructivist' approach to problem-solving, where they are able to take a direct role in the development of their knowledge rather than mimic behavior of the past. They can more quickly overcome their misconceptions as well as acquire a greater degree of interest in the subject matter. In the process they also gain experience in the kind of cooperative, collaborative approach to research that will be characteristic of later stages of their careers. At the moment, however, student- and problem-centered instruction is found in many institutions largely in the form of pilot projects supported by external grants, with special, sometimes Herculean efforts on the part of individual faculty and staff. These successful pilot projects must become the norm, and not the expensive, labor-intensive exceptions in our science and technology curricula.

In addition to mastering the skills and knowledge specific to the field of study, students enrolled in SME&T disciplines will increasingly need to improve their communication and problem-solving skills, to acquiring a positive attitude lifelong learning, and to be able to deal effectively with the ethical dimension of their professional lives. At present few courses in areas of science and technology offer significant opportunities for students to develop facility in oral and written expression, or to pursue broader questions relating to the nature of scientific knowledge and inquiry.

In light of what we now know about the ways in which science and technological development affect the environment, for good as well as for ill, it is also imperative that we afford our students opportunities to reflect on how their actions as individuals will contribute to the larger problem, or to its solution. As David Orr recently put it, "the kind of discipline-centric education that has enabled us to industrialize the Earth will not necessarily help us to heal the damage caused by industrialization."[1]

In thinking about improvements in the quality of education at the college and university level we should also keep in mind that many of our students are entering their programs of study with inadequate preparation and knowledge in the sciences, especially in mathematics. This lack of proficiency manifests itself even in such everyday activities as solving simple proportional equations and graphing X-Y plots. I am aware of a number of reform efforts that are underway at the elementary and secondary level, and many of these show great promise.

The point is that those of us within the higher education community must regard what goes on at the elementary and secondary level of education as our concern as well.

Needed Changes in Institutional Policies

It is my view that to a large extent upgrading the quality of the undergraduate educational experience is a matter of individuals and institutions having the determination to put into general practice the kinds of innovative approaches that have already been shown to be successful in various pilot projects. But, to a very large degree, this moans we must give considerable thought to what we expect our universities faculty to be doing in future years.

A significant number of faculty throughout the nation, and in all disciplines, have some sense of the importance of upgrading the quality of undergraduate instruction. But many others have little desire and incentive to take part. Indeed, to be perfectly frank, a significant percentage of faculty resist taking the time and effort required to incorporate new scientific and instructional technologies within their own instructional activities. And many, perhaps most instructors carry out their teaching assignments with little understanding of the nature of the learning process and which approaches to teaching might be most conducive to their students' learning. At our nations' research universities, most existing faculty performance-assessment and reward systems afford little opportunity for recognizing the effort of those faculty who are prepared to make a major commitment of time and effort to work toward improving the quality of undergraduate instruction. To some extent, then, enhancing the quality of undergraduate education will require a fundamental change in the priorities by which faculty decide how to spend their time, as well as a more learning-focused set of performance reward systems.

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[1] David Orr *Earth in Mind: On Education, Environment, and the Human Prospect.* (Washington, D.C. and Covelo California, 1994) p. 2

The magnitude of the impact of poorly prepared entering students on instruction at the college and university level highlights the importance of improving communication and forging new alliances with teachers at elementary and secondary levels. In my view, improvement in SME&T instruction at the college and university level requires that K-12 teachers participate in the process of setting the reform agenda and that colleges and universities undertake to provide teachers with the kind of preparation and in-service training they will need in order to introduce new materials, concepts, and teaching styles into the classroom. It is essential that we work to increase understanding of the ways in which our nation's educational system is a unified whole. The various levels depend on one another in many ways, but we rarely plan and execute programs accordingly. So here also universities must find ways to support the efforts of teachers at the elementary and high school levels, and to reward the members of the university community who are prepared to build stronger school-university relationships. Thank you very much, Mr. Chairman.

***William English Kirwan** has served as President of the University of Maryland at College Park since 1989. A member of the College Park mathematics faculty since 1964, Dr. Kirwan has played a pivotal role in shaping the destiny of the state of Maryland's flagship campus. In 1981, after serving as Chair of the Mathematics Department for three years, he was appointed to University's chief academic post. As Provost and Vice Chancellor, he raised admission standards, increased the number of merit scholarships and fellowships, and established an academic planning process. When he became President, the University undertook a major restructuring of its academic organization, and a renewed emphasis on undergraduate education. One of the nation’s most respected educators, Dr. Kirwan has served as Chair of the Mathematical Sciences in the Year 2000 Committee, a task force created by the National Research Council to improve mathematics education at the nation's colleges and universities during the next decade, and as charter member of the NRC’s committee on Undergraduate Science Education.*

Testimony Before the Undergraduate Review Subcommittee of the National Science Foundation

Paula P. Brownlee

President, Association of American Colleges and Universities
Washington, District of Columbia

Mr. Chairman, thank you for the opportunity to speak before this committee. I am very appreciative of the chance to share some of Dr. William (Brit) Kirwan's time here. He serves as a member of our Association's Board and provides important leadership to the work of AAC&U. The review that you are undertaking of undergraduate education in science and technology is timely and important, and it is a privilege to join so many fine colleagues in trying to contribute to your efforts.

You are receiving excellent testimony from colleagues representing the disciplines and colleges and universities, whose experiences with advances in science and engineering education are current and in depth. The perspective I bring is that of an association whose activities involve working with academic administrators and faculty leaders across hundreds of universities and colleges.

The AAC&U mission is to strengthen and promote liberal education. We interpret contemporary liberal education as an education that prepares students to best understand, analyze and contribute their developed knowledge to the world they can come to know. Such an education includes the study of the arts and sciences, implies the understanding of interdisciplinary connections and anticipates integration of theory into their lives, lived in a changing world. The study of science and mathematics, engineering and technology all have absolutely essential places in such a liberal education–and for students who major outside these fields as importantly as for those of us who majored within them. My own background includes a number of years as an organic chemist, briefly in industry then in a university, before I moved into campus administration.

AAC&U has long been involved in projects, a number of which have been funded by NSF, which address the improvement of curricula and teaching practices in the scientific disciplines–for undergraduate majors and in general education courses.

Brit Kirwan, in his testimony spoke of "upgrading the quality of the undergraduate educational experience" as being to a large extent "a matter of individuals and institutions having the determination to put into general practice the kinds of innovative approaches that have already been shown to be successful in various pilot projects." He talks of the need for "determination" in order to translate successful pilots into general practice. I think that his "engendering the 'determination' to translate successful pilots into general practice" is a central issue for us. This is the only way we shall ever see widespread improvement in undergraduate science education for all students.

AAC&U works with many hundreds of individuals and campus science and engineering departments, and we are impressed with the range of effective innovations being made. At the same time, too often it appears that the faculty members have thought up their own ideas in relative isolation. A chemistry faculty friend recently said to me: "NSF knows that it is getting good value for its dollar investment in research. But teaching is not the result of training comparable to research, and the reform of teaching often seems to me driven by uninformed bright ideas." Maybe each innovation is too much a separated pilot project. Much of others' testimony will speak well to many of the best practices, and will be important for the review.

We do all lack knowledge of how to spread the best practices for others to access. Once disseminated, how is interested faculty inspired to transmute them into their *own* laboratories, classrooms or technology-aided instruction? I think that complex understanding of this process is needed to successfully propagate multiple improvements.

At AAC&U it is said that we try "to enable our member institutions or departments to do together what they cannot do alone." In earlier decades, our projects aimed to bring together faculty to spark each other's initial ideas around a particular reform. This is probably still the underlying premise of content-filled educational meetings. Sometimes we can return to our own campus ready to adapt the new ideas to our own setting. Very often, however, on our return the initial idea with its attendant energy just dies.

In more recent years, our association has strongly encouraged campus *teams* to participate in our annual meeting; almost all our funded projects now involve teams also. A group of colleagues sharing an off-campus experience can better enable the work to be sustained back on campus. The group brings back a tiny encouraging community.

A continuing use of this practice is in the AAC&U "Asheville Institutes." Two of these, in which interdisciplinary science with humanities general education courses were designed, NSF helped fund. Over the past five summers, 105 colleges and universities have sent five-member teams of faculty and an academic administrator for 6 days. Administrative commitment from the beginning enhances the likelihood of the innovations being adopted and supported on campus. For particular projects, the involvement of a trustee or the president of the institution is required. I cite these examples to illustrate the complexity of the process by which the initial bright idea for the improvement of some aspect of undergraduate science teaching will finally be spread (and often changed en route) to lastingly improve quality.

Wherever dramatic transformation is planned, efforts must be sustained by multiple means. The pairing of institution teams, with occasional trips to each other's campuses, enables exchange of experience at much deeper levels. We are beginning to utilize listserves and other electronic communications; these hold great promise for the future. When a team can stay connected with a project for a year, much more opportunity for help with economic and political issues surrounding the introduction of reforms can occur. In such cases, nationally respected consultants can offer informed assistance. As an example, the lack of faculty rewards for teaching and the lack of recognition for innovative developments are widely cited as a disincentive to reform. Consultant help might offer outside credibility and cite other positive experience.

Sometimes projects falter along the way. A planned final gathering of project leaders can spur sustained effort. The goal is always to achieve students studying well in the reformed curriculum and assuming that good assessment tools are in place. In just one AAC&U project (not one in science education alas!), funding was provided so that we could, several years later, send an outside evaluator to each campus involved. I have the written report now, and I think this is an extraordinarily good means for a funding agency, and others, to know how deeply a reform is rooted. Such evaluations would also inform the design of later funded projects. I believe that this Review Subcommittee might consider this idea further.

I have asked here for you to consider how best to multiply the impact of fine examples of undergraduate curriculum reform. Simple dissemination is not enough, whether by print, electronic or face-to-face means. We are rapidly learning that students learn best when they are enabled to actively construct their own understanding. It is scarcely surprising then, that faculty, too, learn to teach best when they can use others' ideas – out of which they are enabled to construct their own teaching. *Enabled* means having others to talk and debate with, having support to experiment and being recognized for the intellectual effort demanded.

I cannot finish my testimony without adding a word on the continuing needs of women and minority faculty to be supported and "enabled" as creative reformers in the world of science and engineering education. This world is still a more difficult one for a variety of reasons; the past support of NSF is deeply appreciated. Many of us hope it can be sustained.

A final word on the role of graduate education as a preparation for the role of future professor. AAC&U is undertaking, with the Council of Graduate Schools, a project on "Preparing Future Faculty." Under it, Ph.D. students (many of whom are science and mathematics students) at 17 research universities are having a planned "field exposure" to the life of professors at the neighbor college, these graduate students are receiving unprecedented introductions to the professoriate. We are particularly pleased to have minority students in these programs, which we hope will be encouraged to seek faculty positions on graduation. I hope that NSF and other government and private agencies will help us plan ahead for the kind of informed young faculty members we want to design and teach our undergraduate science, mathematics, engineering and technology courses of tomorrow. Thank you.

As president of the Association of American Colleges and Universities (AAC&U), ***Paula P. Brownlee*** *heads the only higher education organization of member institutions that focuses on strengthening liberal education on our nation's campuses. AAC&U was founded in 1915 and is now composed of more than 660 public and private colleges and universities, whose presidents, deans, and faculty members are the active participants. The goals of AAC&U are carried out through its research and publications, projects, national meetings, and specialized workshops. Before becoming president of AAC&U in September 1990, Dr. Brownlee was president and professor of chemistry at Hollins College for nine years. Previously, she was dean of the faculty and professor of chemistry at Union College for five years and a dean and tenured faculty member in chemistry at Rutgers, the State University of New Jersey. She received her bachelor's and doctoral degrees in chemistry from Oxford University and held a post-doctoral fellowship at the University of Rochester before working briefly in chemical industry. She was recently elected Honorary Fellow of her college, Somerville College, Oxford.*

Testimony to the National Science Foundation Hearings on Undergraduate Education

Saul K. Fenster

President, New Jersey Institute of Technology
Edison, New Jersey

I appreciate the opportunity to testify on the subject of undergraduate education in the fields of science, mathematics, engineering, and technology (SME&T). This subject lies at the heart of what we do at New Jersey Institute of Technology. The leadership of the National Science Foundation is exceedingly important to us, and I am delighted to participate in this dialogue.

In 1986, a National Science Board task committee under the leadership of Homer Neal, issued a report that has contributed to significant change in undergraduate education in science, mathematics, engineering, and technology.

That report – an analysis of the weaknesses and findings of traditional attitudes and approaches to SME&T instruction, followed by specific recommendations for reform – set the tone for a decade of rethinking and retooling. Although much remains to be done, I think it is fair to say that the stimulus provided by the National Science Board, and the advice and support subsequently provided by the National Science Foundation, have helped transform the way faculty approach the mission of undergraduate instruction in SME&T fields.

Today I would like to share with you my assessment of the impact those efforts have had at one institution, New Jersey Institute of Technology. I will describe our philosophy of undergraduate education. Cite some of the specific steps we have taken, and offer some comments on what is working best.

A recurrent theme in what I have to say will be *the importance of context.*

Let me begin, therefore, with a bit of context for my remarks. The central purpose of undergraduate education at NJIT is to prepare students for careers as "complete professionals" with the potential for leadership in their chosen fields of endeavor. Let us review for a moment the specific characteristics of such a person. It goes without saying that "professional" conduct implies honesty and integrity. In addition, a "complete professional":

- embraces responsibility
- is technologically proficient
- communicates effectively
- comprehends the interdisciplinary nature of innovative thinking
- can see the totality of an enterprise and the inter-relatedness of its goals
- understands the competitive nature of the marketplace
- is entrepreneurial
- respects the environment

- adapts to change with flexibility
- is a productive and cooperative team member
- appreciates and respects diversity; and
- continues to learn throughout life.

I believe that our success as a nation will depend upon such people. People who can lead in a global economy, keep our corporations at the cutting edge, design and produce goods, employ natural resources in an environmentally benign way and do all these things with respect and appreciation for diversity.

The key, of course, is to provide a comprehensive, well-rounded education that maximizes *all* of the values listed above. The package is incomplete if scientific and technical excellence is sacrificed; but it is also inadequate if the pursuit of scientific and technical expertise precludes attention to the external context within which the science and technology enterprise functions. The old saw about the value of a broadening general education at the undergraduate level holds true today, perhaps more than ever.

How is all this to be accomplished?

There is no simple formula for success. But it is certainly possible to point out a number of contributing factors that have demonstrated effectiveness. Reforms of curricular design and course content, the introduction of improved pedagogical methods and new technologies, the integration of research into undergraduate teaching, and institutional recognition of faculty efforts in undergraduate education are among them.

In each case, NSF has served as a powerful catalyst for change. NJIT and many other institutions have benefited from its guidance and support.

In the balance of my remarks I will try to demonstrate why I make that assertion.

We know that one objective of SME&T education must be to captivate students: we must literally *capture their imagination*, and then we must *hold their interest.* The key, I believe is to teach in context and to give students a realistic preview of the roles played by the engineer, the architect, the scientist, and the manager. With NSF support through the Gateway Coalition and two major grants under the Technology Reinvestment program, we are reconfiguring the shape and content of the undergraduate curriculum at NJIT.

There are a few specific features of the new curriculum

- A new required full-year course, *Fundamentals of Engineering Design*, involves all freshmen in complex, open-ended design problems from the very beginning of the curriculum.
- Traditional freshman humanities and social science courses are coupled to the *Fundamentals of Engineering* course to create a cohesive sequence that emphasizes connections among the fields of human knowledge.

- Multi-lifecycle and pollution prevention concepts will be introduced throughout the curriculum to show students that economic viability and environmental responsibility are essential considerations in developing design solutions.
- We are developing computer-assisted decision-making tools that introduce environmental concern in the form of "clean" manufacturing considerations at every stage of the design process for use in freshman chemistry classes as well as for direct use by industry.
- Our factory floor, summer internships, and cooperative education programs offer immediate hands-on experience.
- A required seminar series will bring to the campus speakers from industry to discuss manufacturing topics from the perspective of their direct experience.
- In chemical engineering, required courses link communication and critical thinking to the analysis of chemical processes, unit operations, and plant design.
- Required courses in economics and management have been combined into a single, year-long course that leads students through the critical financial considerations that must be taken into account in producing goods and services.
- A course for seniors gives them the opportunity to carry out projects from product conceptualization through commercialization as a capstone experience.

Thus, throughout the curriculum, we will provide integrating learning experiences that provide a foretaste of the complexities of the workplace. Students will realize *before* they graduate that professional success depends upon the ability to organize a variety of human resources as well as apply science and mathematics. This is truly science, mathematics, and technology *in context.*

Other new modes of undergraduate education supplement these curricular developments. For example, we now offer undergraduate students the opportunity to work directly with a faculty mentor, thereby experiencing the kind of thinking and experimental activity that goes on in the world of basic or applied research.

The use of computer technology in delivering the undergraduate curriculum also takes the form of distance learning. With the support of the Sloan Foundation, NJIT now offers an entire undergraduate degree program (the Bachelor of Arts in Information Systems) through computer-mediated instruction supplemented by videotapes.

The curricular improvements we have undertaken appear to be having beneficial effects on our students. One indication of this is last year's 85 percent retention rate from the freshman to the sophomore year. Another is the enthusiasm reported by many of our faculty members.

Yet the curriculum as a whole might best be characterized as a "work in progress." It is surely not perfect, nor has it been developed to our full satisfaction. The individual strands I have described have yet to be woven together as a coherent a fabric as we would like to see, with a pattern that commands immediate recognition when viewed from a distance.

The ultimate goal is to educate professionals with a better understanding of their calling, thereby rendering them better prepared to lead others. The means is a curriculum bound together not only by a traditional set of academic objectives that are related to the notion of preparing students for professional practice, but also by a broad thematic expression that represents the profession directly. Real curricular integration demands explicit linkage between and among sources.

A desirable consequence will be higher retention and graduation rates. If the broad thematic motif is sufficiently compelling, it will arouse curiosity and stimulate interest. We can then hope to spur better teaching on the part of faculty and better learning on the part of students.

The challenge to university leaders is to nurture a unity of purpose within the campus community. It is no trivial matter to do this with individuals, both faculty and administrators, who tend to view the world from a discipline-oriented perspective. Moreover, the academic enterprise rightly values individual creativity. Curricular unity must be achieved without compromising the “free market” of ideas, without sacrificing open-ended debate and intellectual controversy.

Clearly, the university community will need more time to internalize the conceptual framework embodied in the new curriculum, and to capitalize more fully on its pedagogical possibilities.

Two additional points arise from the notion of a broad reform of the undergraduate curriculum based on integrating themes.

First, undergraduate education does not take place in a vacuum. The next generation of faculty is emerging from Ph.D. programs across the nation. They will be expected to teach a new undergraduate curriculum. It follows that the nature and content of Ph.D. programs themselves deserve reconsideration, especially in the SME&T fields. If we need faculty attuned to new approaches in undergraduate education, we should deliberately build the necessary components into our doctoral programs.

Some of the necessary components are obvious. More emphasis on making interdisciplinary connections and on filling the lacunae in the matrix between the disciplines. More opportunities to teach. More emphasis on preparing for non-academic careers by working in teams and learning leadership skills. More emphasis on the roles of quality and cost in an era of global economics. More emphasis on the need to realize the commercial value of research.

Second, I cannot leave the matter of undergraduate curriculum without reference to the training of schoolteachers. Since so much more can be accomplished when the interest and motivation start at an early age, the teaching of “SME&T in context” should begin in the elementary and secondary schools. It therefore stands to reason that colleges and universities, and – more importantly – those individual faculty members who know how to teach SME&T in context, should be playing a central role in the education of future K-12 teachers of math and science, rather than institutions and faculty whose primary focus is on pedagogical methods. And there should be far more interactions between elementary/secondary schools and universities that teach the sciences, engineering, and technology.

The faculty reward system is another powerful tool.

As I see it, the distinction between a Ph.D.-granting institution and other colleges and universities is *not* based on a difference in the importance attached to undergraduate education. NJIT's academic culture is defined by the presence of a faculty engaged in undergraduate instruction as well as graduate education, research, continuing professional education, and professional practice. The faculty's experience of research and professional practice adds freshness and excitement to the classroom and the laboratory. They integrate what they have learned from their own work into the material they teach. The unity of teaching and research is becoming a way of life at NJIT precisely because it contributes powerfully to excellence in professorial education.

Once again, NSF support has encouraged us in the right direction. With two grants under the CRCD (Combined Research-Curriculum Development) program, new graduate courses will incorporate current faculty research in the fields of particle technology and optoelectronics, and the fundamentals can be integrated into undergraduate courses long before they appear in textbooks.

That said, it remains necessary to remind faculty that the university values undergraduate instruction.

NJIT’s promotion and tenure processes emphasize good teaching as well as research productivity. In the review of each candidate for promotion and/or tenure we examine the record of teaching – including curriculum and course design, advisement, and very importantly the results of student evaluations. No one who is rated less than “good" as a teacher is recommended for advancement, regardless of the individual’s intellectual research record.

Recognition can take other forms as well. NJIT has a program of annual awards for excellence in teaching. I can report that faculty take great satisfaction from the recognition they receive from their peers and from students. Some have been heard to say with pride that they devote themselves primarily to teaching undergraduates.

The transition from school to college can be particularly difficult for students interested in the SME&T fields. Most of them come with no prior experience of what to expect, or what will be expected of them. The high national rates of attrition from collegiate SME&T programs can be attributed in part to this discontinuity.

At NJIT we approach the problem in two ways.

First, we think some prior experience provides a useful bridge to college. In 1970, we started a pre-college program in urban engineering with 30 high school students from the Newark area. Today, with support from a large number of foundations and corporations, our pre-college programs have expanded to include 3000 students per year from elementary school through high school and several hundred teachers. One program, funded by NSF since 1990, introduces rising 8th and 9th graders to research in the fields of environmental science and civil and environmental engineering. All of these programs provide a foretaste of college and are designed to plant the seed of interest in the fields of science, engineering, math, technology, and architecture as potential careers. Again, teaching in context.

To assure greater continuity for students who begin their college careers at community colleges, a consortium of New Jersey colleges and universities that includes NJIT, together with local industries, high schools, and professional societies, has been awarded another NSF grant to create a national center of excellence in engineering technology education. The center will develop a model associate degree program in Mecomtronics Technology [*] and work toward the restructuring of existing engineering technology programs.

The second approach, one that has become standard at many colleges and universities, is to provide far more extensive orientation and adjustment programming than was traditionally the case. At NJIT this takes the form of a pre-freshman year summer orientation experience we call "miniversity," a first semester freshman seminar designed to develop early awareness of the attitudes and behaviors that contribute to long-term success in college; an "early warning" system designed to call attention to students who may need special advice, tutoring, or counseling; and an academic advisement system that operates from the first semester through the senior year.

It is also important to emphasize fuller participation by members of groups underrepresented in the SME&T fields, especially women and minorities. I say this for two fundamental reasons: First, fuller participation is a simple matter of equity. In light of the long history of social inequities, attempts to deal with the effects of economic and educational disadvantage are desirable on purely moral grounds. Beyond that, however, America's future depends to a large extent on our ability to assure an adequate supply of well-prepared professionals, people who can keep our corporations at the cutting edge and provide leadership in a global economy. The nation needs more such people, and will find them *only* if previously under-represented populations participate.

The confluence of a compelling moral imperative with the human resource needs of the twenty-first century constitutes a powerful mandate to higher education.

Institutions such as NJIT have a special role to play. We believe that this university's complementary and mutually reinforcing goals of excellence and access clearly reflect the responsibilities of a public institution with a public mission.

In this area, too, the National Science Foundation is providing leadership and support.

I would like to close with a sobering thought. It is the realization that our agenda is incomplete. Colleges and universities understand that they occupy a unique position in-service to the Nation. We think we have fulfilled this role well in the past, and we want to do so in the future. What we need from Washington, from our state capitals, and from our many other partners, is some assurance that the value of higher education will be recognized in the form of continuity in our sources of support. With tangible support from the National Science Foundation and others, higher education will continue to enrich our future and that of generations to come.

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[*] "Mecomtronics" is the engineering technology discipline that combines the areas of mechanical and electronics technology, and computer hardware and software systems linked through telecommunications.

Saul K. Fenster *is the sixth President of New Jersey Institute of Technology. He earned a Bachelor degree from the City College of New York, a Masters Degree from Columbia University and a Ph.D. from the University of Michigan. He has authored or co-authored two textbooks and numerous research papers and technical articles. His current board memberships include the New Jersey Commission on Science and Technology, Research and Development Council of New Jersey, which he chairs, the National Action Council for Minorities in Engineering and the Liberty Science Center. He is a member of various committees of the American Association of State Colleges and Universities and the National Association of State Universities and Land Grant Colleges. He is a fellow of the American Society of Mechanical Engineers and a Fellow of the American Society for Engineering Education, and a member of the American Association for the Advancement of Science the Society of Manufacturing Engineers, and the Council on Competitiveness.*

Needed Improvements in Science, Mathematics, Engineering and Technology (SME&T) Education, and Institutional Policies that Would Aid Undergraduate SME&T Education

Judith A. Ramaley

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What our nation's colleges and universities face today

Colleges and Universities are facing a number of external pressures that create tensions among the competing values of affordability (cost), quality of programs, and access. These pressures include: 1) financial constraints brought about by the redistribution of state funding from higher education to other purposes such as corrections and school equity funding; 2) demands for increased accountability and enhanced productivity; 3) expectations that higher education will make student learning its central purpose and introduce values and social responsibility into the curriculum; and 4) concerns about the employability of new graduates.

In response to these pressures, ten percent of this nation's colleges and universities sharpened their missions in the past year and 70 percent began to examine the contributions and productivity of their academic departments. This climate of renewed concern for responsibility and accountability and the growing emphasis on the importance of student learning provides an ideal opportunity for institutional leaders to reassert the importance of the preparation of teachers, for K-12 and for higher education. To emphasize the need for the introduction of significant reforms at both K-12 level and in higher education in SME&T for both students who plan to major in these fields and for students who do not.

Undertaking radical change

At the same time, institutional pressures affect the ability of our colleges and universities to undertake the major transformation of their science, mathematics, engineering and technology curricula, which are needed if we are to enhance the capacity of this nation in these disciplines. Also, to advance the ability of our citizens to make informed decisions utilizing information from these fields.

Radical rethinking of academic programs entails genuine rethinking of the entire educational enterprise, including the design and content of the curriculum, the creation of a new institutional environment through the design of many aspects of campus infrastructure, a new approach to faculty and student roles and responsibilities, and the use of unusual and creative inter-institutional and interdisciplinary partnerships. Observers of academic reform have observed that reform this sweeping is rare. More commonly change is sporadic and occasional, progresses in fits and starts, and is characterized by bouts of housecleaning followed by years of inertia (after J.B. Lon Hefferlin, *Dynamics of Academic Reform* Jossey-Bass, 1969).

What creates a supportive environment for reform?

To succeed in such an ambitious undertaking, an institution or a cluster of institutions, must have adequate time and financial resources, access to knowledgeable advocates who are committed to transformational change, and a campus and academic environment that is receptive to outside influences. In our experience, institutions that are at the edge of the academic mainstream because of their youth or the recent emergence of their institutional type (e.g. regional colleges, urban universities), or because they enjoy unusual and creative leadership, are more likely to undertake a genuine, rather than a piecemeal change process. These kinds of institutions are not likely, however, to be sought out by policy-makers seeking to identify promising and productive models for educational reform.

Once an institution embraces the importance of transformational change, it helps to have: 1) continuity of leadership; 2) a supportive governing body; 3) partners in the community who offer ideas and shared resources, as well as alternate learning environments; 4) outside resources from foundations, mission-related agencies such as NSF, and consultants who promote change through offering financial resources, political support, and the validation needed to affirm and support both the necessity and the value of change; and 5) a number of venues for discussing curricular reform, exchanging ideas, and participating in peer-reviewed and invitational meetings and workshops.

The role of institutional leaders in supporting improvements in SME&T education

Many colleges and universities, whatever their mission, have experienced "mission creep" toward the values and expectations of research institutions as faculty have sought to develop individual scholarly careers using the strategies that they learned in graduate school. To link what faculty do more effectively to the particular mission of the institution; academic leaders are turning to the redefinition of faculty roles and rewards and are focusing on the academic department as the primary focus of support both for individual faculty development and for the collective responsibilities of the faculty in organizing and offering the curriculum. During these discussions, there is an opportunity to introduce curricular reform as priority areas of faculty activity that will be supported by the institution.

In addition, some new approaches to interdisciplinary programs have been introduced across the country in recent years. These efforts can provide additional opportunities for students to integrate what they are learning and apply what they know to community issues that require multi-disciplinary approaches.

Presidents, Provosts, and Deans can encourage the trend toward a broader mission-related definition of faculty scholarship and faculty roles by providing incentives at the institutional level and the departmental level for both individual faculty excellence and for collaborative teaching and research that crosses departmental lines. Effective curricular reform that reflects recent changes in K-12 education as well as changing needs of employers who will hire our graduates requires close collaboration between faculty in education programs, engineering and business and arts and sciences as well as cooperation with local public schools and other post-secondary institutions. Often campus policies, campus support structures and campus rewards do not assist faculty who work on curricular reform or K-16 reform and who must spend significant time in the field or in collaborative activities with colleagues on campus in other disciplines.

To increase the importance attached to the improvement of SME&T education and to provide a supportive environment for curricular reform, administrators can do a number of things:

1. Utilize a clear campus mission statement as a framework for defining the goals and aspirations of the institution. Make clear to everyone, including trustees, faculty, staff and students, that constant curricular advancement is an important campus priority and that every graduate of the institution should be able to use scientific and mathematical problem-solving techniques and information competently and confidently.
2. Personally acquire a thorough knowledge of educational reform efforts in public schools and in higher education and speak consistently and knowledgeably about the importance of the reform of graduate education to incorporate both the acquisition of research and teaching skills and a familiarity with contemporary issues in curricular reform, and K-16 curricular reform itself by articulating the importance of designing the goals and outcomes of a college education upon the foundation provided by the reform movement in K-12. Talk with faculty about these issues regularly.
3. Encourage the reinterpretation of faculty roles and rewards to make them compatible with the demands of educational reform, teacher preparation in SME&T, interdisciplinary and collaborative research and teaching, and community-based work.
4. With faculty guidance, create a campus infrastructure and policies that support the activities needed to support curricular reform on campus, to reflect changes occurring in the public schools as well as employer expectations, and to promote the exploration and the reform of graduate education in SME&T. This will require, introducing new assessment strategies that evaluate student learning and that document the outcomes of curricular reform as well as providing technical assistance for faculty who engage in curricular innovation at both the undergraduate and graduate level.
5. Provide opportunities for faculty to discuss educational reform with their colleagues in workshops and campus-wide seminars.
6. Support faculty who are interested in educational innovation and in graduate education by providing campus resources such as mini-grants and release time for such work.
7. Participate in national discussions of faculty roles and rewards as well as K-16 and graduate educational reform and encourage faculty and staff to do so as well. Where appropriate, subsidize the cost of travel to such conferences and meeting in the same way that the campus encourages faculty to participate in discipline-based professional meetings and workshops.
8. Be prepared to invest in educational reform and in new faculty roles and responsibilities, drawing resources from a restructuring of campus administrative operations or redistributing resources from academic programs that are no longer in high demand.
9. Encourage institutional partnerships with other organizations to encourage innovations in education and to provide a supportive environment for faculty involvement in the local community.
10. Encourage a greater local understanding of the importance of SME&T education and K-12 reform by participating in community efforts to improve the local schools. The

local Chamber of Commerce or other local business associations often sponsor such activities.

11. Activities of this kind offer occasions for colleges and universities to introduce discussions of how high school must prepare for post-secondary education as our nation's post-secondary institutions continue to improve SME&T education. While there has been a lot of talk about the need for a high skills workforce, many employers still want only reliability, basic skills, and good attitudes towards customers and fellow workers, and are not yet introducing the elements of a "high performance" environment into their business practices. As a result, universities and colleges must work simultaneously to promote higher standards of performance for their students and for the organizations that will employ their graduates.

Graduate education has to change, too

There is a growing demand for universities to become concerned with the issues of society in the hopes that our involvement will help to clarify the competing values that are at stake, frame clear and critical questions, and build a wider repertoire of responses that will rebuild the workings of civic life in this country and the core of democracy itself. If colleges and universities become properly engaged with our communities, we can become the source of social capital for a new era. A critical component of this capacity-building must be provided by SME&T education. We must prepare the next generation of college and university faculty to offer the kind of undergraduate education that our students really need.

We must take a long hard look at how we prepare graduate students now. What are we really doing in our graduate curriculum and in our research programs? In higher education today, are we really building social capital, which sociologist Robert Putnam describes as "features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit," and are we preparing people who can create and work within such networks? Are we preparing a generation of faculty who can design a curriculum that can accomplish these goals and, themselves, model for their students a more interactive and collaborative form of learning and discovery? Will our graduate education put teaching and research on an equal footing by introducing values, skills, and professional goals that encourage a balanced career?

The process, rooted in the 19th century, that has led to greater and greater differentiation of academic life into definable disciplines, each with its own world view and culture and objects of discourse, has drawn our process of socialization of new scholars into the academy further and further away from the influence of the questions and concerns of the citizens who support us.

Do we really know whom we are preparing in our masters and doctoral programs and how they will use their education? What principles should we adopt to guide the design of our graduate studies as we think about what responsibilities our graduates will undertake after they complete their formal education?

One problem we have in higher education is that we are trapped in our own, still successful, model of graduate education. We are proud of saying that graduate education in this country is the envy of the world. We still continue to attract talented students from around the world to study in our nation's universities. Our model of a research-based doctorate has served as a *world* model for preparing scientists and engineers as well as scholars for other fields.

So, why should we question a clearly successful enterprise? The problem is that this model works effectively for a smaller and smaller percentage of the students who enter doctoral study and then take positions at our nation's research universities. The others, who will find employment elsewhere, are less well prepared.

According to a recent study completed by the National Academy of Sciences Committee on Science, Engineering, and Public Policy, we are producing students who are prepared for traditional research roles while employers are calling for doctoral graduates who have expertise in more than one discipline, who can collaborate across fields and in various settings, who can adapt quickly to changing conditions and learn in new fields and who work well with other people. Furthermore, we are preparing our graduates to join us in the academy, while more and more of them will find employment elsewhere in business and in government.

How can we promote more versatility? Faculty today needs both disciplinary strength and the ability to interpret and apply disciplinary perspectives in collaborative settings. The faculty we are hiring now and will hire in the future will need to be able to work effectively together to create opportunities for meaningful involvement of students, community members, and local practitioners in SME&T education. They will require: a) *communication skills* including the ability to listen well; b) *collaboration skills* which include the building of mutual trust and respect, ability to problem-solve in complex groups with different experiences, goals, and definitions of success; c*) time management skills* - the need to spend time creating a common set of goals, a common vocabulary, shared definitions of success with partners from other organizations; and d) *team-building skills* - the ability to work with many different kinds of people with different expertise and motivations.

If we really need faculty with these skills, we will need to recognize these competencies and achievements as significant factors for promotion and tenure and during the distribution of discretionary salary increases and other faculty rewards.

Genuine teamwork and partnership are difficult modes for faculty to adopt who have only operated within disciplinary-based frameworks, where in most cases, the questions, the assumptions and the methods of inquiry are agreed upon and understood by everyone involved. Partnerships require time, trust and patience, and a different repertoire of skills, skills that can be incorporated into our graduate and professional programs.

Few institutions are actively addressing graduate education as yet, but the time is rapidly approaching when we must do so. In *Campus Trends 1995*,[1] Elaine El-Khawas reviews the results of a survey sent to an array of 506 colleges and universities. Of our peers, only 10 percent report extensive change going on at the graduate level, 70 percent report some, and an alarming 21 percent report no activity at all. If we approach this new challenge in a way similar to our commitment to active/service learning for undergraduates, we will again find ourselves in the forefront of a concern that many people are talking about, acknowledge must be addressed, but are reluctant to approach.

There is no doubt in my mind that we must reshape graduate education in SME&T, both at the Masters and at the Doctoral level. In preparation for this, we must take time to retrace the same steps that the faculties who are redesigning our undergraduate curriculum are taking. We must ask: Who are our students? What are they experiencing and why do so many students fail to achieve their educational objectives or take so long to do so? What do our students plan to do with their education? What is happening to the marketplace for people with an advanced education?

Let us bring this challenge close to home. With respect to our own colleges and universities, what attributes and skills will we seek as we hire a new generation of faculty? Are our doctoral programs likely to produce the kinds of versatile faculty we would want on our own campus? Will our new faculty be prepared to undertake the collective responsibilities that are required to deliver a curriculum of the kind we have recently introduced? One that requires teamwork and cross-disciplinary perspectives? Will they know how to conduct effective community-based research with partners from other programs, institutions, and community organizations?

Might we define a kind of "general education" for graduate students, similar to the goals we have for our undergraduate students - a set of goals or principles that will guide us to design opportunities for our graduate students to develop advanced problem-solving skills, communication skills, collaborative skills, an appreciation for diverse viewpoints, an ability to continue to learn, and an ethical and socially responsible basis for their research and practice?

Can we design a different form of professional development for teaching and research assistants that provides mentoring and school and business and industry based experiences?

What can NSF do to reinforce and support the changes that will be necessary to create a genuine K-16 SME&T reform movement and to assist institutions that wish to redesign the study of SME&T at the college levels for both majors and non-majors?

1. Provide individual investigator awards for research on the-impact and sustainability of instructional innovation. We need research on fundamental questions concerning teaching, learning and assessment in undergraduate SME&T education.
2. Provide support for summer workshops that bring students, parents, community participants, and faculty and public school teachers together to work on community problems and to engage in curricular reform. Provide summer stipends for the faculty who design and participate in these summer programs. Faculty who do research during the summer can often obtain two full months' pay to support their time spent doing research. Faculty who engages in curricular innovation or in summer workshops and K-16 initiatives do not have access to such funds. This sends a signal that basic research is valued more than K-16 initiatives or curricular innovation. In addition, although it is understandable that NSF would want to stretch its resources as far as possible, these programs are often under-funded and the financial condition of most of our colleges and universities precludes any significant local supplements to the project budget.
3. Make provision in undergraduate research awards for introducing new faculty into the process and for supporting faculty teams. The current funding levels for REU

grants do not allow for variations in the faculty configuration or encourage the mentoring of graduate students or new faculty by more experienced faculty.

4. Provide opportunities for faculty who are engaged in curricular reform to present their work and to publish their findings in invitational and peer-reviewed publications and conference proceedings.
5. Take a leadership role through both advocacy and financial sponsorship in persuading more professional societies and professional journals to provide exposure for exemplary work in undergraduate and graduate curricular reform.
6. Recognize that curricular advancement is an on-going process and requires sustained faculty support. While workshops and conferences can stimulate an interest in reform and promote the exchange of ideas, continuing assistance will be necessary for faculty who plan to apply the ideas generated in these workshops and summer projects to their on-going courses and curricula. This support can be provided in the form of release time, graduate assistants, and periodic gatherings to review and interpret the results of work to date. It is becoming increasingly difficult for universities to offer this support. Most NSF-sponsored projects can only launch a change process. In the normal 2-3 year time span of a grant, work can barely get underway. Requirements to demonstrate actual changes in student achievement in such short time frames can actually interfere with the change process by forcing the participants to focus on very short-term goals. It is better to evaluate very concrete outcomes such as the development of new curricular materials and courses, effective involvement of faculty in the exploration of new techniques in teaching and learning, and the like. If possible, projects should be funded for 3-5 years to provide the sustained support needed to move from design to introduction of a new curriculum to accurate and effective assessment of the impact of the new approaches on student learning, competence, and confidence. In addition, the current grant process often results in a succession of faculty being involved, when in some cases, it may be important to keep at least a core of participating faculty together for a longer period of time, introducing new participants according to the nature and development of the project.
7. Graduate programs must require participation in work on curricular reform as well as offer significant teaching opportunities. NSF fellowships and training programs can promote this by emphasizing the importance of teaching, curricular reform, and interdisciplinary work. Annual and end-of-grant reports should include a request for information about the nature and impact of activities of this kind conducted under the sponsorship of the grants.
8. We must find ways for all undergraduates, both majors and non-majors, to have an opportunity to do “real” research, and to do so throughout the undergraduate experience, not just in a limited number of distribution courses that satisfy a science or math requirement. At Portland State University, we involve undergraduates who enroll in our *Science and the Liberal Arts* curriculum in active research projects over the full four years of their undergraduate curriculum because of our belief that the habits, values, and ethics of the SME&T disciplines must be practiced and learned over a long period of time. This is true for both non-majors as well as majors. SME&T taught in conventional ways using standard textbook and laboratory exercises is about as interesting as reading an instruction manual. Furthermore, this

approach addresses only one type of learning style and disadvantages students who learn best in other ways. Taught as a liberal art, however, SME&T courses for both majors and non-majors call human curiosity to attention and make such inquiry and learning a deeply satisfying and imagination-expanding experience. The liberal art of mathematical, scientific, and technical inquiry allows our faculty and students to try out – to test – their imaginations for accuracy, precision, credibility and acceptance by a community of knowledgeable peers. NSF can offer sponsorship for such experiments at any institution willing to undertake the significant and radical reform necessary to introduce this kind of curriculum.

9. After years of under-funding, our nation's instructional facilities and equipment are badly out of date and there is a enormous need simply to provide better laboratory and classroom environments. We must upgrade our equipment remodel our classroom and laboratory spaces to accommodate new approaches to learning and we must make significant investments in technology such as computers and telecommunications. The accumulated need for retrofitting and new equipment would vastly exceed the ability of any Federal source to support, but NSF could develop ways to encourage additional support for these needs by its use of equipment funds. The emphasis recently has been on the need for curricular reform. This is frustrating to many faculty, including many at Portland State University, who have already made radical changes in the curriculum, introduced new pedagogical approaches, established new areas of emphasis–including the use of interdisciplinary and cross-disciplinary options to tailor the educational experience of individual students to reflect their educational goals more directly, and used community interactions and partnerships to create richer learning environments for our students. What these faculty need now is the equipment to support the curriculum, the encouragement to solidify the reforms that the have already begun, and the resources to assess the results of what they have done.

10. It is unclear whether the goal of the investments made by NSF in undergraduate education are designed to identify and support innovative work or to promote an overall systemic improvement in the level and impact of SME&T education and research capacity in this country. Often the process of preparing a proposal and doing the necessary work to show the feasibility of a project are extremely worthwhile for an institution undertaking significant reform for the first time. But if the ideas are not new to the community-at-large, even though they are innovative at the applicant institution, will NSF decide to fund the project? This poses a significant policy question for NSF. Is it better to generate and facilitate the distribution of new ideas and positive results or is it better to build the nation's core capacity to provide effective SME&T undergraduate education by providing incentives to encourage institutions willing to undertake major curricular reform. This key policy question deserves serious attention.

11. NSF support programs for new faculty should include attention to teaching, general education, and the reform of SME&T curricula. In general, so should regular research grants. Whenever possible, a research program can effectively include undergraduates, and, in some cases, serious high school students. This should be encouraged where feasible and the grant review process should include a knowledgeable review of the potential benefits for undergraduate education and K-16

articulation. NSF can powerfully shape the focus and emphases of grants for research and education in science and engineering by calling for a thorough discussion of the human resource implications of the work to be done and requiring a thoughtful analysis of the outcomes. The Application Guide published in October 1992 (NSF 92-49) had an extensive section on this (p.4), which appears to have been omitted from later application guides.

12. Wherever possible, projects should be funded that connect reforms in SME&T undergraduate education to the rest of the liberal arts. Reform undertaken in conversation and in collaboration with faculty in the humanities, social sciences and fine arts can stimulate fresh thinking throughout the university and reinforce the efforts being made by SME&T faculty. This practice can direct more faculty attention to undergraduate education and advising, the dissemination of improved practice, and the effective integration of reform efforts across the curriculum. NSF can play a truly catalytic role in promoting changes in the entire undergraduate experience through encouraging effective linkages of SME&T reform with both the rest of the liberal arts curriculum and to professional education in engineering and technology.

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Elaine El-Khawas. *Campus Trends 1995.* New Directions for Academic Programs. Higher Education Panel Report, Number 85. American Council on Education, July 1995.

Institutional Perspectives of College and University Leaders

David Ward

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Madison, Wisconsin

Introduction - University of Wisconsin-Madison Programs

Thank you for the opportunity to be here today. The issue of science and math competency at the undergraduate level is one of obvious importance to us and to society. As an institution of higher learning, the University of Wisconsin-Madison has labored much in recent years to come to grips with a problem that threatens our quality of life and our ability as a nation to compete in the world market. The absence of broad science literacy poses significant dilemmas for society and for higher education itself.

Over the past 10 years, the community of scholars at Wisconsin and elsewhere has pursued broad and far-reaching initiatives to attack the problem of science competency. To its credit, the National Science Foundation has also strongly encouraged change at research universities through its own programmatic initiatives. These joint efforts are laudable and they merit continued support and experimentation. The research university must play a critical role in the improvement of science education. That role must include new and stronger relationships among different kinds of educational institutions, and better connections between our primary and secondary schools and higher education.

At Wisconsin alone, there are many examples of programs that seek to alter, reform or redirect the way science, math, and engineering are taught. The teaching and learning infrastructure is being rebuilt, and it is being connected in new ways with schools, students, teachers and the other critical components o£ the educational system.

Through entities such as the Institute for Chemical Education and the Center for Biology Education, universities like Wisconsin are creating new tools for learning. Thousands of students across the country and at all educational levels now have the opportunity to track genetic change through generations of plants in a single semester, thanks to the Wisconsin Fast Plants Program. Memory metal and other materials science innovations are becoming integrated into freshmen chemistry courses around the country, refreshing a dated curriculum. These are two examples from Wisconsin of research university-based innovations that are having broad impact.

This year at Wisconsin, with the support of NSF, faculty is embarking on an ambitious program to revamp the way chemistry is taught nationally at the college level. Employing the latest instructional technology, offering new contexts for learning and incorporating the most effective cooperative learning techniques, these researchers will attempt to make the first sweeping instructional changes in decades.

Wisconsin has established a teaching academy for faculty as a mechanism through which to identify, through evaluation, exemplary teaching practices, and to support widespread application of the best techniques across disciplines and curricula. Superimposed on these and other activities is a state-of-the-art means of evaluation through our LEAD Center. It is crucial to acknowledge the need to measure steps taken and to hold claims to improvement to a critical standard.

Thanks in large measure to the track record of educational innovation of some of Wisconsin's most distinguished researchers, the university has now been given the opportunity to enter into an interdisciplinary partnership with NSF known as the *National Institute for Science Education*. This unique partnership is expected to yield new strategic and tactical means of building the nation's science and math education infrastructure.

There seems to be no shortage of creativity among the faculties of research universities. However, tradition-laden institutions like universities must find more effective ways to sustain innovation.

Issues

Science for All. There is a critical need now for colleges and universities to more broadly and effectively integrate science, math and technology into the general education curriculum. Science is a significant and pervasive influence in the lives of all Americans, and universities need to do a much better job of preparing all of our students – not just science and engineering majors, to think more analytically and to live in a world increasingly shaped by the forces *of* science and technology. The earlier we can do that in the course of a student’s education the better. Of critical importance is providing a seamless but flexible connection between high school science and the very first science experiences of higher education.

Changes in Higher Education. We need to envision the classroom of the future and not simply improve the traditional classroom approach to learning. Faculty who invest time, energy and creative power to enhance the learning environment or develop new learning tools should be encouraged to apply for educational grants with the same conviction brought to bear in the quest for research grants. In addition the reward system for faculty must evolve to recognize the importance of work by those who break new instructional ground.

Empowering Teachers and Future Teachers. Moreover, we need to do much more to develop our faculty and future faculty, to empower them to be effective innovators in science education. The academy needs to look beyond its own borders, expanding the involvement of staff and teaching assistants in the development and application of innovative teaching techniques and styles. The research university can play an important role by providing our graduate students with more exposure to innovation in the learning process and especially to cross-fertilize the research interest with the general dialogues about science.

Evaluation. It is also very important that universities begin to evaluate seriously novel learning approaches. Critical evaluation and assessment must be integrated into a system through which we can identify, develop and disseminate the most effective approaches to learning. Given all the resources that have been provided for education reform over the last decade, there are relatively few devoted to measurement of success or failure. It is essential that we incorporate some kind of outcome assessment into our education reform efforts. In addition, we must strive to communicate these results, make them accessible, and then act on them. This is a daunting task. At many of our institutions, obtaining the quantitative data – grades, retention rates, demographics – requires effort on the part of the investigator. The data are simply not available in most places. Rigorous qualitative analysis is even rarer.

Fortunately, instructional technology is providing us with a wealth of new feedback opportunities, such as electronic mail. At research universities electronic mail is greatly enhancing access to faculty and staff and is providing timely information on the successful comprehension of course material. A spate of questions on a particular lecture topic – delivered by electronic mail – provides a compelling signal to the lecturer that he or she missed the mark. A student too shy to sign up for a face-to-face appointment may find the courage to send an e-mail with a pressing question. Faculty and staff ought to be strongly encouraged to make greater use of these now almost-commonplace technologies.

A Changing Infrastructure. Another set of related and pervasive issues lie in our infrastructure and the evolution of new technologies and instructional materials. Will the formal classroom exist a decade from now? This is an area of rapid development that outstrips the ability of any single institution to manage and guide it. Who will take leadership in identifying effective approaches? Will the academy recognize and reward contributions by faculty members in this arena? If not, how will we move forward?

We also must recognize that technology costs money. Who will pay? While the information superhighway is changing the way many of us function, we must be aware that very large numbers of students – from kindergarten to college – do not have access to this technology. To help remedy these inequities, we must begin to explore new partnerships with the private sector and others that have a stake in a technologically literate workforce.

Equity and Diversity. Equity and diversity within our institutions are critical and related issues as well. The demographics of the twenty-first century demand that we renew our commitments to access and opportunity for all. Human resources are our greatest asset and the needs of the twenty-first century will require the inclusion of the full diversity of our population in order to avoid squandering valuable intellectual resources.

Making Better Connections. Universities must also become catalysts for the development of new networks between different types of institutions. Research universities do not exist in an institutional vacuum, nor do they have a monopoly on education. We must use existing programs such as our summer programs, integrated general education for non-scientists, and distance learning to help us weave a web of learning between different educational systems.

The Value of Existing NSF and Other Programs

Clearly, research universities can change creatively in partnership with NSF and other funders. NSF and other federal and private granting organizations have already made serious investments in innovative and effective improvements in science education. These investments now need to be better connected to a rapidly changing learning environment and the possibilities of a new networked educational system. Continued and expanded support of these developments is needed to drive change.

NSF and other granting entities can begin to require some kind of relationship between research proposals and their broad impact on science education. This strategy has been discussed at a number of national meetings on science, math and engineering education, and is likely to provide the kind of motivation needed to encourage pilots and experiments.

In closing, I would like to thank you again for the opportunity to express some views and ideas of how research universities can and should change to foster change in the science education landscape. We are committed to addressing this problem and we look forward to continuing our partnerships with NSF to attain a common goal.

***David Ward** was named chancellor of the University of Wisconsin-Madison in June 1993, becoming the 25th individual to serve as the university's chief executive. Ward had served as interim chancellor since January 1993. Ward became vice chancellor for academic affairs at UW-Madison in 1989, and in 1991, he was also named provost, chief deputy to the chancellor. His UW-Madison faculty career spans 30 years, and he holds the Andrew Hill Clark Professorship of Geography. For the past eight years, Ward has provided strong leadership for efforts to improve the quality of undergraduate education. The next step, says Ward, is to redefine undergraduate education, not simply through improvements of existing programs and processes, but by developing new ways for learning to occur on college campuses. To that end, he recently published a comprehensive strategic planning document, outlining priorities for the next decade as the university attempts to balance its teaching, research and outreach missions. Ward has given new expression to The Wisconsin Idea, the venerable philosophical framework for the university's public service role. The Wisconsin Idea is embodied by a vast array of partnerships between the university and both the public and private sectors, says Ward, from economic development activity and sharing of faculty expertise to educational collaborations with K-12 schools.*

Presentation Before the National Science Foundation Undergraduate Review Subcommittee

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Thank you, Mr. Chairman, for inviting me to participate in today's hearings on undergraduate education in engineering, science and mathematics. I have chosen to depart somewhat from the suggested format of comments in order to provide the subcommittee with a brief overview of the work of the task force I chaired in 1985 which resulted in the issuance of NSB Report 100-86, which has served to guide NSF development in undergraduate science, engineering and mathematics education over the past decade. I will also share with you a current initiative in which I am involved, that bears on undergraduate science education at our nation's research universities, as well as some of my own thoughts about the important changes that we must consider with respect to undergraduate education in the future.

Charge to the NSB-100 Task Committee

At the start of the work of our committee in 1985, the charge we were given was as follows:

> . . . to consider the role of the National Science Foundation in
>
> "undergraduate science and engineering education . . .to determine what is an appropriate NSF role in undergraduate science and engineering education . . . and to examine what are possible mechanisms for carrying out that role. Should NSF move to establish undergraduate science, engineering and mathematics programs, apart for support for undergraduates provided in some research grants? Should NSF have a role in shaping undergraduate curricula?..."

We set about the task of collecting data in just about every imaginable way. We reviewed extensive literature on the subject, consulted with higher education organizations and held several hearings in Washington at which faculty, university administrators, federal agency officials, and industrial leaders testified, in much the same way as the current hearings are planned.

What we learned was not very reassuring. Among the key problems we uncovered were:

- deteriorating quality of the college-level science-educational infrastructure
- laboratory instruction that was typically, "uninspired, tedious, and dull."
- lack of opportunity for faculty to update either their disciplinary or their pedagogical skills
- outdated curricula that failed to convey the essence or excitement of contemporary science
- declining student interest in careers in science, engineering, or mathematics, or in education in these disciplines

In looking back over the years since our report was completed one can sense that real progress has been made at NSF in undergraduate science and engineering education:

- A new Office of Undergraduate Science, Engineering and Mathematics Education has been established and now administers or monitors over $100 million dollars for undergraduate programs.
- A new program to provide research experiences for undergraduates has been established, the REU program. Indeed, Director Bloch initiated the REU program while our committee was still in the midst of its hearings, being immediately convinced that this was an activity much needed and very much in keeping with the mission of NSF.
- A new program for undergraduate faculty enhancement has been established.
- A new curriculum development program has been established.
- A special undergraduate curriculum development program in calculus has been developed and, from all indications, the results are very positive.
- A new instrumentation and laboratory improvement program has been developed.

There can be no doubt that NSF has taken the recommendations of our committee very seriously, and that the leadership actions of NSF have had an impact on other agencies and foundations. For example, the Howard Hughes Foundation initiated its own program for support of undergraduate education shortly after our report was completed and has already committed many millions of dollars in this area. Leadership was, and still is, an extremely important element of NSF actions.

Changes Over the Decade

Indeed, the leadership that NSF shows in the years ahead will be critical. Since the issuance of NSB Report 100-86, there have been an enormous number of developments that will potentially influence the nation's commitment to undergraduate science education and which must certainly be taken into account as plans are made for advancing undergraduate education. As unlikely as it may have seemed in 1986, we have seen the end of the Cold War. This single event raised the hope that, by unleashing resources that might be more productively directed toward the overall improvement of life for our citizens, education needs could be more adequately addressed. But it also raised the question as to what extent a large technically educated workforce would be needed, given the apparent diminished national security requirements. Coincident with the change in the balance of world power has been the realization that the U.S. federal budget deficit must be reduced and that federal outlay will be made with a heightened degree of scrutiny. Though many voices caution against neglecting investments with long term benefits, there will be an increased tendency to focus federal and state resources on major issues of immediate urgency – a recipe that often neglects the needs of higher education.

There are further developments that serve to shape the environment within which policies and practices in undergraduate science and engineering education must exist. As a result of a few highly publicized incidents in recent years, there has been some erosion in the public's confidence in its higher education system. Compounding the effects of these events are the ever-present debates about indirect costs, high tuition, and stories of the difficulty some students claim in gaining access to faculty, who are characterized as only being interested in their research.

While we note the growth in the total number of baccalaureate degrees over the past decade – rising by almost 20 percent – it is also of interest to note that the number of degrees in the natural sciences and engineering has fallen by almost 20 percent. We note that undergraduate enrollments in laboratory courses continue to fall. Furthermore, though there has been significant growth in NSF budget for education and human resource activities, we note that most of this growth has been primarily in the K-12 programs.

These are issues that it will be critical for NSF to address in the years ahead, as we try to craft undergraduate education in science, engineering, and mathematics for a rapidly changing world. I also believe that, while NSF has a key leadership role to play, it is also incumbent upon universities themselves to think more creatively than ever in trying to deal with *these* same issues.

In Search of a New Compact

Over the past year, several research vice presidents at Midwestern universities have been engaged in a cooperative effort to construct what might be the principles that would guide the partnership between research universities and the federal government in the decades ahead. I might note that, given the end of the Cold War, many of the original guideposts in the Vanovar Bush era are no longer viewed as being sufficient to fully determine what the relationship should be between universities and the federal government.

In the quest for developing these principles, we have had numerous discussions with officials in the Executive Branch, with several leaders in Congress, and with industrial leaders. It is our hope and expectation that these consultations will continue in the months ahead and will culminate in one or more symposia where these items will be discussed in more detail.

What I can report to you today, however, is strong support for universities participating with the government to ensure a strong program of research and education in the sciences, engineering and mathematics.

In the set of draft principles we have developed to date is the following reference in the section on education for the next century:

- Education for productive life in an age that is information intensive, technologically demanding, culturally complex, and globally competitive.
- Education that will continue to assist our citizens in adjusting to the rapid changes in the modern world.
- Public understanding of the key technological, economic, cultural and social issues that we face."

Our draft report continues:

> ". . . education of the nation's citizens for productive life and work is one of the primary function of the research universities, and a function to which they can bring unique assets. One of the greatest strengths of the research university has traditionally been

> graduate education – the training of new generations of scientists and scholars. The same assets of the university that have made our doctoral programs the envy of the world can be turned, and are being turned, to improvements in other areas of education as well. Universities, in addition to training the next generation of researchers, seek to instill in their undergraduate students the culture of rational inquiry, and the skills to be effective workers and knowledgeable citizens. In our rapidly developing world, education is more than ever a life-long process; this implies that one of the most important outcomes of undergraduate education is the ability to think clearly and to learn effectively. It also implies that universities have a larger role to play in ongoing education and in serving as a resource that the broader public can draw upon in trying to understand new issues and problems that arise."

Our report also notes that,

> "universities should seek, review, and implement ways to further utilize their research competency to enhance undergraduate education, by expanding opportunities for undergraduates to participate directly in research and scholarship; and by endeavoring that all students who graduate have attained the necessary levels of scientific and cultural literacy . . . universities should explore creative ways to make their resources for knowledge and understanding available and accessible to the public; they should explore and implement ways to facilitate timely public understanding of important scientific and technological issues; they should be increasingly receptive and responsive to public interests and concerns and should seek to facilitate meaningful dialogue between the public and academic communities."

I must note again that these statements are taken from a document that is still in draft form – and that not even all of those vice presidents who have been involved in their development are necessarily in complete agreement with every phrase as it currently stands. Nonetheless, I also note that this document has gone through a number of iterations and extensive discussion. I believe that, in its current form, it already represents a well-founded distillation of considered thinking about the issues, from a number of sources.

Two things have become abundantly clear from these discussions: since 1986, universities have made a great deal of progress in enhancing undergraduate science and mathematics education, utilizing the resources available from NSF that I mentioned above, as well as from other sources, including internal sources. At my own university, for example, direct participation by first- and second-year undergraduate students in research projects has been growing at a substantial rate for the past several years. The Chemistry, Mathematics, Geology, and Physics departments have all undertaken major successful reform of their introductory science curricula. Such experiences are, I am sure, increasingly widespread among institutions of higher education.

It has become clear that universities must think even more broadly comprehensively, and creatively about undergraduate education. The pace of change in the world that our undergraduates enter upon graduation appears to be accelerating. In addition, with enhanced technology, the typical means and methods of education have the potential to change dramatically. These changes place the traditional obligation of undergraduate education – to provide a well-rounded education – in a new light. It will be incumbent upon us to employ the new technologies wisely and to be innovative in our mapping of a liberal education onto the demands of the current world. In this regard, the recently announced NSF program on Comprehensive Undergraduate Science Education Reform is a welcome addition to NSF portfolio.

I would like to set forth just two ideas, by way of example, of the kinds of discussion in which I would like to see major research universities engage internally, as we confront the need to enhance undergraduate education.

First is an idea that I have proposed for discussion at my own institution: namely, that the university consider requiring that all undergraduate students at some point in their undergraduate career have some direct participation in research. Whether such a university-wide requirement is feasible for the University of Michigan; whether one should focus instead on providing opportunities for all students to engage in research; or whether, indeed, one should focus on building research experiences more directly into courses. These are all issues that have been discussed as alternatives to the original proposal. The underlying point of them all, however, is the one that I think universities must take very seriously: with all of the research taking place at a major university. There must be some way to harness it, to utilize it in inculcating in students the sort of appreciation and understanding for science and rational inquiry that comes best as a result of relatively direct experience.

The second idea has to do with the rapid changes in information technology, and the impact that these changes will have upon undergraduate education. What should we think, for instance, about the importance of the classroom and the laboratory to science education, when technology will soon make possible more dispersed, distributed, and virtual means for learning the basic facts? How do we ensure that new educational technologies do not simply contribute to an information glut but instead are used to help our students genuinely learn how to use information effectively, i.e., how to get it, evaluate it, and convert it into knowledge? One can imagine education proceeding without any classrooms as we understand them today, but it is hard to imagine education proceeding without some direct guidance from those who are truly skilled in the development and use of knowledge. Can we imagine, then, a university without classrooms, where "courses" are available electronically, and every undergraduate student is engaged in a research team?

In the above comments I have focused on the role of research universities, because that is the setting for the current initiative in which I am involved. But, as in our findings in 1986, I must note the seamless link of the contributions to undergraduate science education issues by the entire spectrum of institutions, including community colleges, four-year colleges, research universities, and museums.

Concluding Remarks

I would like to take this opportunity to congratulate the National Science Foundation and the National Science Board for convening this current set of hearings. Clearly, there have been sufficient changes in our world to fully justify taking a fresh look at where we now stand in undergraduate science and engineering education, and to chart a course that will guide us through the next decade, which will be one far from what any of us could have envisioned in 1986.

Undergraduate science and engineering education, and the partnership required between universities and the federal government to ensure that the highest quality experiences are provided to our students, is as important now as ever. The work done by the Board and Foundation over the past decade has clearly laid the groundwork for increasing the appreciation of the importance of undergraduate science and engineering education to our nation. Now what is needed is a refinement in the strategies and goals to make sure that progress continues.