# SHAPING THE FUTURE OF TEACHER PREPARATION IN SCIENCE AND MATHEMATICS

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Recently, I spent an exciting hour with a group of elementary teachers who had won national awards for excellence in teaching science and mathematics. It was energizing to visit with them about their work - and it was very reassuring to know that they are out there in those classrooms getting young people excited.

I was there to make a brief presentation about the National Science Foundation (NSF) report on undergraduate education in science, mathematics, engineering, and technology (SME&T), *Shaping the Future* [1], developed by an NSF review committee that I chaired. In particular, I asked for their suggestions about how to improve undergraduate programs for prospective teachers. A major emphasis of the report is on teacher preparation, and, in the months since the report was issued, I've become even more persuaded that teacher preparation is a vitally significant aspect of undergraduate education that is too often treated as a stepchild by institutions of higher education. So, I sought the advice and suggestions of these excellent elementary teachers.

They responded with enthusiasm, and with considerable criticism of the usual teacher education programs. One of their major messages was that prospective teachers must get out into real classrooms, with real master teachers, much earlier and much more often than is normally the case. They essentially said that being taught in college classrooms how to teach children was not effective. I wish I had been able to have the benefit of their experience and to have similar encounters with other fine K-12 teachers during the months that *Shaping the Future* was being drafted, as the report would doubtless have been even stronger and clearer about changes that must come in the preparation of those who teach science and mathematics to our young people.



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**Charge to the Committee**

The first NSF report on undergraduate science, mathematics, and engineering, issued in 1986, (the "Neal Report," named for Homer Neal, the chair of the committee responsible for the report) was directed almost exclusively to the program for preparation of majors, particularly those who were heading for graduate school and eventually a PhD in a SME&T discipline. When Luther Williams, Assistant Director of the NSF for Education and Human Resources, initiated the review that led to *Shaping the Future*, he was explicit about our charge. The purpose of the review was to "consider the needs of all undergraduates attending all types of two- and four-year colleges and universities," addressing "issues of preparation of K-12 teachers in these fields, the needs of persons going into the technical work force, the preparation of majors in these areas, and the issue of science literacy for all."

In the process of developing *Shaping the Future*, the review committee solicited written opinions from some 150 faculty, administrators, professional society officers, and corporate executives about the state of undergraduate SME&T education in the mid-1990's. We also had oral testimony provided by panels of faculty from the various disciplines, of college and university administrators, and of employers (including one school superintendent who employs hundreds of new teachers every year). The opinions of the SME&T community about teacher preparation in these fields are reflected in *Shaping the Future*, which summarizes them as follows: "Many faculty in SME&T at the postsecondary level continue to blame the schools for sending underprepared students to them. Bur, increasingly, the higher education community has come to recognize the fact that teachers and principals in the K-12 system are all people who have been educated at the undergraduate level, mostly in situations in which SME&T programs have not taken seriously enough their vital part of the responsibility for the quality of America's teachers. The Neal Report devoted one brief sentence to teacher preparation, for example (though much more to teacher enhancement). But, virtually every participant in the review work of this committee has expressed concern over the way the undergraduate SME&T education community is working in the preparation of teachers."

**Teacher Preparation**

It seems obvious to me that the undergraduate community should be concerned about the effectiveness of its teacher preparation programs as an important part of its responsibility to the general society it serves. But I also believe that higher education has an inherent

self-interest in the quality of K-12 education. As our report points out: "With a more intensive and effective commitment on the part of institutions to the preparation of K-12 teachers, colleges and universities can raise their expectations about the preparedness of entering students. One way to do that might be for institutions to enter into "treaties" with the secondary schools providing that, after a certain date, credit will not be given at the collegiate level for remediation in SME&T."

SME&T departments have in the past usually played a more active role in the enhancement of teachers already out in the field than in teacher preparation programs for current undergraduate students. This generalization is doubtless too broad, as most generalizations are. But NSF summer institutes for teachers and other programs, such as MAT graduate programs, have been important means by which SME&T faculty and departments have become involved in K-12 education. Such enhancement programs will continue to be important means of helping teachers learn new content materials, curriculum ideas, and pedagogical methods. Professional development for teachers will continue to be of great importance in maintaining and strengthening quality elementary and secondary education.

But my colleagues and I on the review committee for *Shaping the Future* were persuaded that unless increased attention is paid to the quality of the undergraduate program for prospective teachers, we will never hope to be able to mount a sufficiently comprehensive enhancement program to keep up with the need. That is, we must do more to "turn out" a quality product at the beginning - and then we can do what is needed to help those quality teachers stay current, excited, and growing in knowledge and ability.

**Key Recommendation**

The overarching recommendation of *Shaping the Future* is key to thoughtful examination of teacher preparation programs in particular. That recommendation is that:

> *All students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and processes of inquiry.*

We must examine each of the two phrases in this central recommendation. The first calls for education that is both excellent and supportive. For my view one of the best validated pieces of educational research is that students tend to learn at the level they are expected to learn. There have been many experiments demonstrating the "Cinderella effect", that if teachers believe that their students are capable of learning and convey that expectation to the students, presenting challenging material to them, the students will generally learn more than if they are taught in the context of lower expectations. Not only does the kind of preparation students need for life in the 21st century require excellence of education; the expectation that students will excel is likely to result in increased learning as well.

But SME&T education must also be supportive. *Shaping the Future* includes lots of feedback from students and others about the intimidating nature of instruction in most SME&T courses. Most of us recognize that too many SME&T departments take pride in how many students fail their courses, in how "tough" those courses are. It is almost as though many faculty believe that high expectations are incompatible with caring, nurturing, and supporting the learning of students. I disagree. Science and mathematics are hard, and students come into college courses in these fields with a lot of baggage of past bad experiences, failures, and fears. Those faculty who teach these courses should recognize these concerns and do everything possible to meet the students where they are, without lowering reasonably high expectations.

Our central recommendation has a second part that is also important. I introduce this topic with a story. I once attended a meeting in Minneapolis with Bruce Alberts, President of the National Academy of Sciences. At the meeting were several teachers and administrators from public schools, present to discuss science and mathematics education in K-12. One of the major topics was the need to incorporate inquiry and discovery into science and mathematics. One kindergarten teacher remarked that she had been teaching kindergarten for 25 years and had used "hands-on" methods in her teaching for the last several of those years. "But it was not until last summer," she continued, "when I had an opportunity to work for several weeks in a faculty laboratory at the University of Minnesota that I ever understood what 'inquiry' meant."

It is a major failing of our SME&T education system, I believe, that students are not

generally led to understand that doing science and mathematics involves asking questions. SME&T is more than giving answers to already-researched questions. As a result, most people in society have little idea what is involved in research and do not understand what a scientist means when she says something is "true". There is little appreciation that advances in science and mathematics are in large measure cumulative, so that results that seem "useless" at the time may be vital links in finding a very practical application at some point in the future. Several years ago, for example, coral reefs were being decimated by an invasion of the crown of thorns starfish, leading to very deleterious effects on various fish populations. Scientists at the time knew very little about this starfish and so were not able to suggest effective means of control. I wondered at the time what people would think about a grant from the NSF to a biologist to study the sex life of the starfish; yet, the knowledge gained from such a study might have been of great utility to the fishing industry.

*Shaping the Future* notes that there has apparently been a decline in the offering of laboratory-based courses at the undergraduate level, probably as a result of departmental decisions about budget reductions in the face of financial constraints. But our recommendation about the necessity to incorporate the "methods and processes of inquiry" into our courses is not the same as recommending more laboratory courses. Far too many of our laboratories are of the cookbook variety, in which students follow step-by-step instructions designed to reproduce a long-understood phenomenon. In too few cases are students given the opportunity to formulate questions and construct experiments in order to examine possible answers to those questions. As a mathematician, I particularly regret that almost never in courses before the graduate level are mathematics students given an opportunity to create conjectures and try to decide if they are actually provable theorems.

All you have to do is to think about how many people misunderstand the word "theory" - as in "Theory of Evolution" - in order to see how we have failed, as educators in science and mathematics, to help people learn what our disciplines are really about, what scientists do and how they do it. It is far more important for the non-specialist to understand the methods - and limitations - of science and mathematics, the nature of scientific "truth", and how to interpret scientific claims in daily life than it is to have memorized the periodic table of elements or to have learned all the vocabulary in an introductory college text in chemistry.

This major recommendation of *Shaping the Future* - that all students have excellent and supportive educational programs that incorporate the methods and processes of science - has a lot of implications for teacher preparation. First, courses taken by the prospective teachers themselves (who are certainly included in "all students") should have these characteristics. One of the most important things for SME&T faculty to keep in mind is that future teachers of science may be more likely to teach science in the same way they were taught than they are to teach in accord with the pedagogical principles they were taught. For instance, to have a course in methods that stresses inquiry learning in biology may not overcome the influence of several courses in the biology department that were taught in a lecture mode, with emphasis on memorization and incorporating routine follow-the-instructions laboratories. SME&T faculty should be aware, as they teach many introductory courses, that potential teachers of their field are learning from them, not only disciplinary content facts, but also how to teach.

But in addition to influencing the courses for prospective teachers, the *Shaping the Future* recommendation must also apply to what prospective teachers are taught about their role as educators. Their preparation should help them in very practical ways understand how to nurture inquiry and discovery in children without sacrificing rigor or content. It should make them as ready to excite students about science learning as to solve the quadratic equation. We who are in SME&T fields likely got here because we found our field exciting; perhaps some particular teacher or teachers led us to delight in this kind of learning and discovery. We, in turn, should help all our students - and especially those who are going on to teach others - rekindle that sense of delight. *Shaping the Future*, quotes a columnist in The Washington Post, Steve Twomey, writing about the first birthday of his son, Nick. "My son tries to pick up holes ... He tries to pick up shadows, too. There is nothing he won't try to pick up, because there is no such thing as an uninteresting object, and I'm really kind of jealous. Nick has a full sense of wonder, and I don't anymore." I believe that we must nurture that innate sense of wonder as we prepare teachers of science and mathematics.

**Other Recommendations**

*Shaping the Future* contains many more specific suggestions for improving teacher preparation programs as well. These include:

To state governments and statewide higher education boards

Collaborate with external accrediting agencies to make strengthened science, mathematics, and technology standards for K-12 the norm in accrediting teacher education programs.

Teacher education programs must prepare prospective teachers to use, comfortably and effectively, national and state standards in science and mathematics. This means that faculty in higher education must be familiar with the standards in their fields and incorporate them into their courses as appropriate.

To college and university governing boards and administrators

Create or strengthen an institution-wide commitment to the preparation of K-12 teachers and principals, bringing together departments of education, SME&T and other departments, K-12 staff, and employers of teachers to design and implement teacher preparation programs having substantial SME&T content and stressing rigorous standards, along with emphasis on engaging students in learning.

There is a lot here I want to comment on. First is the stress on teacher preparation as an institutional priority. On too many campuses, such programs are viewed as the responsibility of the department or school of education, usually on the periphery of institutional awareness and having low prestige and priority. But the preparation of teachers involves - among others - departments of mathematics, chemistry, English, and history. To help a person become a teacher of content who can excite and nurture a young mind and who is committed to human development as a high calling seems to me a very interdisciplinary undertaking, eminently worthy of institutional commitment at the highest levels. Think what it would do for teacher preparation programs to have the governing board and the president lift up this area as a major responsibility of the entire university, a central aspect of the institution's service to society.

Second, note that we include principals as well as teachers. I believe that the principal in a school sets a tone that is very important in determining the amount of learning that goes on. We need to help prospective (and in-service) principals understand how to create the kind of climate that empowers teachers and nurtures students.

Third, note the emphasis on "bringing together." There is, on nearly every campus, far too little meaningful conversation between SME&T departments and those in education. There is seldom any joint discussion of what prospective teachers need, how to make content and pedagogical principles work together, and how to assess the readiness of students to be good teachers. Even beyond this kind of faculty and departmental collaboration, K-12 teachers must also be part of these conversations and centrally involved in the design of teacher education programs. This was the point stressed by the award-winning elementary teachers mentioned at the beginning of this article. I believe it is an even more important point than is reflected in *Shaping the Future*. Our master teachers have much to offer beginners in the way of experience and encouragement. In addition, however, the most important message a big city school superintendent gave our review committee was that the new teachers he hires have little understanding of who the students are, the kinds of home environments from which they come, and the kinds of attitudes and backgrounds they bring with them to the classroom. Now one may wish that today's students were just like we were, but the fact is, they are not. The superintendent's point was that the teacher preparation programs his new teachers come from did not adequately help the students learn about the kinds of students they will actually have in their classes. To do that seems obviously to require that prospective teachers spend more time in school classrooms with real students, seeing good teachers who teach content while they handle problems of motivation and discipline and deal with a diversity of languages, cultures, and learning styles.

To SME&T Faculty

Develop partnerships and collaborations with colleagues in education, in the K-12 sector, and in the business world, to improve the preparation of teachers and principals.

I recently invited a group of young faculty in science and mathematics to think of things they could do to foster such collaborations. Knowing the kind of pressure these young faculty are already under, I asked them to restrict their attention to ideas that would not take more than 3 hours of time or cost more than $10. Some of the ideas were predictable but no less valuable - such as inviting a colleague in education to lunch; learning which students in a course are prospective teachers and meeting privately with them to encourage and recognize them as well as to ask for suggestions on making the course more relevant to their particular interests. One of the group said that he is a department chair and has a faculty member in his

department who is the official "liaison" with the education department; but the chair had never talked with that faculty member about this role - what the faculty member actually did as liaison and how the chair could help. The chair said he would correct that immediately upon his return home.

To The National Science Foundation

Expand support of K-12 teacher preparation programs - especially through the NSF Collaboratives for Excellence in Teacher Preparation program, where we would recommend funding only projects that clearly incorporate the principles of effective SME&T education (as identified in *Shaping the Future*) and show promise of reaching a larger fraction of those entering the profession.

The National Science Foundation plays a significant leverage role in teacher preparation, through funding of grants and contracts. It must apply that leverage carefully, so as to reinforce the kind of excellent but supportive programs that we recommend - programs that bring together all the important players in the preparation of teachers and that include the methods and processes of inquiry.

## Conclusion

The review committee for *Shaping the Future* was persuaded that we in higher education cannot criticize the K-12 sector without pointing the finger at ourselves for not taking as seriously as we should teacher preparation as part of our task. What more important activity is there than participating in the development and maturation of a young person, and what more important educational activity can there be than preparing undergraduate students to do that well? We salute our colleagues who are devoted to this task and call on the rest of us - faculty and administrators alike - to join them in this cause. ■

## Reference

[1] *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (NSF 96-139), National Science Foundation, Arlington, VA 22230, 1996.