LYNN ARTHUR STEEN

Out from Underachievement

To sustain scientific innovation in the 1990s and beyond, we need to revitalize school mathematics today.

On the national political stump, education has joined motherhood and apple pie. In numbing unison, Republicans echo Democrats and conservatives support liberals in arguing that education must be a top national priority.

Much of the concern with education centers on our diminishing international competitiveness. The evidence is indisputable that in a world of multinational corporations and international markets, inventiveness in science and technology—rather than abundance of labor or natural resources—is the major asset available to U.S. industries. But equally indisputable is evidence that U.S. leadership in science and technology is rapidly diminishing; as a nation, we are simply not renewing our intellectual capital.

Because of the widespread utility of mathematics in scientific and technological applications, mathematics education is a key predictor of scientific competitiveness. Yet, recent international studies—such as the aptly titled *The Underachieving Curriculum,* based on the Second International Assessment of Mathematics Education—show that the mathematics yield of U.S. schools is substantially less than that of other industrialized countries and far below the levels necessary to sustain our nation's present position of leadership in scientific inventiveness.

To make matters worse, the immense impact of computers on science and mathematics compels major reexamination of objectives and standards for school mathematics. Not only has computing changed the way mathematics is used, thus altering the balance between essential and peripheral topics, but computing has mathematicized science and technology. No longer is it sufficient for theoretical scientists alone to have a working knowledge of mathematics; now all scientists—indeed, virtually all professionals—encounter mathematical models in much of what they do. Contrary to common belief the ubiquity of computers in the workplace means that today's students need more rather than less mathematics.

Calls for change

The Carnegie Foundation recently launched a major initiative to overhaul the teaching profession. It calls

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for radical changes in the way teachers are educated and in the way schools are operated, all designed to ensure that teachers grow as professionals with increasing respect, autonomy, and responsibility (and commensurate compensation). Such changes, according to Carnegie, will enable teachers to improve the quality of education.

In a similar spirit, three national reports in mathematics and science education are due to appear this year or next, sponsored by the National Council of Teachers of Mathematics (NCTM), the Mathematical Sciences Education Board (MSEB) of the National Research Council, and the American Association for the Advancement of Science (AAAS). Although these undertakings differ greatly in detail and purpose, they generally agree that schools must increase student involvement in learning by fostering a broad view of mathematics, by increasing use of computers, by linking mathematics to science, and by stimulating student-led projects.

Meanwhile, governors, state legislatures, and school boards are resolving to improve what happens in schools by increasing emphasis on accountability. By basing the allocation of resources on actual performance, political leaders expect free-market forces to ensure survival of the fittest in educational programs. They argue that greater competition, and the application of higher standards, will enable administrators and teachers to assess results and act accordingly to improve the quality of their schools.

Not surprisingly, educators, politicians, and scientists do not speak with one voice. For example, increased emphasis on assessment usually leads to less autonomy for teachers and more emphasis on skills, while greater stress on student involvement in learning tends to make assessment more difficult.

Nonetheless, the basis of a national consensus is forming. Now, not only can political candidates tell us that they believe in education, they can actually do something about it: They can stress five areas—expectations, testing, learning, teaching, and education—as planks for a national platform to support our children (and our country) as we prepare to enter the twenty-first century.

Expectations

Independence is the hallmark of U.S. educational policy, which is set not by the U.S. Department of Education but by 16,000 local school districts. Local control of education is deeply embedded in the American body politic, a legacy of constitutional authority that reserves to the states all matters not expressly granted to the federal government.

Yet this independence is largely a myth, especially for mathematics education. Effective control comes not from Washington bureaucrats, but from invisible state committees that approve textbooks and anonymous officials who administer standardized tests. Few facts stand undisputed in educational research, but the dependence of teachers on textbooks and of students on tests is as deep an insight as exists in this amorphous discipline: teachers teach only what is in the textbook, and students learn only what will be on the test.

The result for mathematics education is a de facto national curriculum. It is an “underachieving” curriculum that follows a spiral of constant radius, each year reviewing so much of the past that little new learning takes place.

Some states (such as California, Texas, Wisconsin, and New York) have recently promulgated new standards for mathematics education, often with surprising consequences. In California, new standards led to initial rejection of all mathematics textbook series submitted for authorized adoption—principally because the texts failed to adequately develop student capabilities to address and solve complex, subtle, and unpredictable problems.

To focus attention on the *national* need for improved standards in school mathematics, the National Council of Teachers of Mathematics is preparing a detailed report spelling out important new goals both in content (by grade level) and in instructional practice. These standards speak about what is necessary and what is possible in today’s mathematics classroom: that students should learn not only arithmetic but estimation, measurement, geometry, statistics, and probability—all the ways in which mathematics occurs in everyday life—and that they should gain confidence in their ability to communicate and reason about mathematics.

These new standards specify, for example, that all children in primary school should learn to use estimation techniques whenever appropriate, to use calculators as tools for computation, and to explore alternative strategies for solving problems. Statistical ideas permeate the standards from primary grades ("use data to make predictions; experiment with concepts of chance") to high school ("design a statistical experiment and communicate the outcomes"), because statistics permeates the society in which we live.

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We must judge schools not by remembrances of things past but by necessary expectations for the future. Members of school boards, accrediting agencies, and state legislatures must first educate themselves about these new standards, and then insist that they actually be used by school districts to evaluate the mathematics education they provide.

Testing

Governors all over the country are talking about "assessment" in order to raise expectations and evaluate programs. And with good reason; assessment is an integral part of teaching. It is the mechanism whereby teachers can learn how students think and what they are able to accomplish. Assessment is also used to evaluate student performance, to compare classes and schools, and to place students in future courses or careers. Because assessment is so pervasive and has such powerful impact on the lives of both students and teachers, it is very important that assessment practice align properly with curricular objectives.

Unfortunately, assessment in mathematics education is rarely used properly. Tests designed for diagnostic purposes are used for evaluation of programs; scores from self-selected populations (e.g., takers of the Scholastic Aptitude Test) are used to compare districts and states; and commonly used achievement tests stress simple skills rather than sophisticated tasks, not because such skills are more important but because they are easier to measure.

As we need standards for curriculum, so we need standards for assessment. Both those who ask for assessment and those who use the results of assessment must ensure that we test what is of value, not just what is easy. In the past, assessments have emphasized computational and mimicry aspects of the curriculum, at the expense of such "holistic" expectations as the student's ability to formulate problems, invent strategies, develop lines of argument, and communicate reasons. That's like judging student writing solely on the basis of spelling and grammar, without paying any attention to what the student is trying to say. Rather than merely validate computation with multiple-choice, right-or-wrong questions, we must seek ways to assess such mathematical traits as flexibility, imagination, persistence, and skepticism.

Some will argue that tests cannot change rapidly lest new data be incompatible with past records. That is an argument for preserving the status quo, no matter how outdated it is. By confusing means and ends, by making testing more important than learning, it holds today's students hostage to yesterday's mistakes.

As new standards emerge for school mathematics, assessment must change to match the entire breadth of curricular objectives. If tests do not change, nothing will change. Conversely, there is no more rapid way to improve mathematics education than to change the standards for assessment. Agencies charged with ensuring quality education—governors, legislatures, state departments of education, and accrediting agencies—have the power to make or break present efforts to improve mathematics education by the way they control assessment practice. States and schools must match assessment practice to new standards of instruction.

Learning

Despite mountains of daily homework, mathematics is primarily a passive activity for most students: teachers prescribe, students transcribe. Most teachers present mathematics as established doctrine, employing a "broadcast" metaphor for learning that stresses right answers rather than clear, creative thinking. In the early grades, arithmetic becomes the stalking-horse for this authoritarian model of learning, sowing seeds of expectation that dominate student attitudes all the way through college. What mathematics teacher isn't plagued with the query "Can't you just tell me the answer?"

Yet educational research provides unequivocal evidence that students learn mathematics well only when they explore it on their own, constructing strategies that bear little resemblance to the canonical examples presented in standard textbooks. Just as children need the opportunity to learn from mistakes, so students need an environment for learning mathematics that provides generous room for trial and error.

Classes in which students are told how to solve a quadratic equation and then assigned a dozen homework problems to learn the approved method will rarely stimulate much lasting mathematical knowledge. A far better strategy is to let students encounter such equations in a natural context; explore approaches to solutions including estimation, graphing, computers, and algebra; and then compare various approaches and argue about their merits. To learn mathematics, students must act out the verbs—"examine," "represent," "transform," "solve," "apply," "prove," and "communicate"—in the new curriculum standards.

In the long run, it is not mathematical skills themselves that are particularly important—for without constant use, skills rapidly fade—but the confidence that one knows how to find and use mathematical tools whenever they become necessary. Only through the process of creating, constructing, and discovering mathematics can this confidence be built.

To encourage students to create, discover, and construct as they learn, states must establish guidelines for the environment in which learning takes place. Administrators and school boards must provide teacher aides, appropriate equipment, and reasonable class sizes so that active learning is possible. And then they must insist that learning actually *be* active.

Teaching

In a sense, no one can teach mathematics. What we hope is that a good teacher can stimulate a student to *learn* mathematics.

For this to occur, teachers need to know how to explore, to guess, to test, to estimate, and to prove. They need confidence that they can respond constructively to unexpected conjectures that emerge as students also explore, guess, test, estimate, and prove. Too often, mathematics teachers are afraid that someone will ask a question that they can't answer. Insecurity breeds rigidity, the antithesis of mathematical power.

At every level, but especially in their college and university courses, prospective teachers should learn their mathematics in a manner consistent with the style in which they will be expected to teach—as a process of constructing and interpreting patterns, of devising strategies for solving problems, and of discovering the beauty and applications of mathematics. Above all, courses taken by prospective teachers must create in these teachers confidence in their own abilities to help students learn to appreciate the richness and excitement in mathematics.

So here is a task for colleges and universities: teach teachers as we would have them teach. It will not be easy to find sufficient faculty well equipped for this task, for college mathematics is, on the whole, presented in the same authoritarian manner as school mathematics. After all, teachers teach as they were taught. Perhaps the National Science Foundation should stress quality teaching in science and mathematics even as it stresses quality research, as much to redefine the academic reward system as to stimulate innovation in undergraduate instruction.

Teacher education

Two recent reports by the Carnegie Commission and the Holmes Group of major universities recommend abolishing the undergraduate major in education as a necessary first step for reinjecting quality in public schools. These recommendations are based on two laudable objectives: to ensure that teachers are well grounded in the subjects they teach, and that able students are attracted to careers in teaching.

Those who would teach mathematics need to learn contemporary mathematics appropriate to the grades they will teach, in a style consistent with the way in which they will be expected to teach. They also need to learn how students learn—what we know from research (not much, but important), and what we do not know (a great deal). And they need to learn enough about science, technology, business, and social science so that they can convey mathematics in the contexts where it most naturally arises—in measurement, graphing, prediction, and data analysis.

Because mathematics is one of the few disciplines taught throughout the entire 13 years of school (K-12) and sequential growth is a firm pre-requisite for moving from one level to the next, the education of elementary school teachers is especially important. Yet the United States is one of few countries in the world that continues to pretend, despite massive evidence to the contrary, that elementary school teachers are able to teach all subjects equally well. The reality is that elementary teachers too often take just one course in mathematics, approaching it with trepidation and leaving it with relief. Such teachers are unlikely to inspire children to have confidence in their own abilities to construct mathematics appropriate to their lives. Often, experienced elementary teachers move up to middle grades (because of imbalance in enrollments) without ever learning any more mathematics. It is profiles such as these—not universal, but not at all uncommon—that compel thoughtful people to say that enough is enough.

We must modify expectations, testing, learning, teaching, and teacher education all at the same time.

It is time that we educated a cadre of elementary mathematics specialists well prepared to teach young children both mathematics and science in an integrated, discovery-based environment. To bring this about, states must alter certification requirements to encourage effective use of such teachers. For example, math/science teachers can be paired with language arts teachers in the primary grades; alternatively, a math/science specialist could lead faculty development in an entire school. Meanwhile, universities must implement new mathematics courses with instructors who will inspire prospective school teachers to grow with confidence.

Strategies for change

It is not enough to say that education is our number one priority, or that we must emphasize science and mathematics to improve our international competitiveness. We need concrete policies and programs for implementing a broad new mathematics agenda. We must avoid piecemeal approaches and their inevitably modest effects: When most of the complex educational system remains fixed while only parts of it change, little improvement will result. We must therefore modify expectations, testing, learning, teaching, and teacher education all at the same time.

That may sound like a pre-scription for a revolution. But it can be achieved, far more effectively, by punctuated evolution. Because mathematics education involves millions of people, the system cannot change quickly. Instead, strategies for change must be orchestrated so that everyone moves in the same direction, at the same time. Above all, we must avoid the temptation of quick fixes or simplistic solutions.

Coordinating a nationwide plan to improve mathematics education is a serious challenge to political leaders. Scientists and mathematicians, for example, can set standards for their disciplines and illuminate productive pathways for educational progress, but they rarely know how to operate in the educational arena. Educators generally know how to change various pieces of the puzzle, but they rarely have either the perspective or the power to effect large-scale change.

Leadership to improve mathematics education must therefore move beyond academe to the broader arena of public policy, provided such leadership is informed by sound understanding of the issues. The agenda should include the following:

- Promote high expectations of school mathematics based on new standards rather than old "basics."
- Disavow simplistic proposals and mindless comparisons of test scores.
- Require that official assessment instruments match current curricular objectives.
- Fund summer programs for talented youth to nurture a new generation of teachers and scientists.
- Encourage widespread use of calculators and computers as tools for calculation and instruments of discovery.
- Create incentives for universities to support quality undergraduate teaching as strongly as quality research.
- Require that all new teachers meet current standards for professional preparation.

- Provide ample opportunities for continuing mathematical education for all who teach school mathematics.

Details of this agenda will appear in reports to be issued during the next several months by both the Mathematical Sciences Education Board and the National Council of Teachers of Mathematics. Every governor, every legislator, and especially our next president should use these reports to help frame an effective policy for revitalizing mathematics education. Our goal for the 1990s must be to make mathematics a pump rather than a filter in our nation's educational pipeline.

Recommended reading

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