Technology and Equity in Mathematics

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"Our lives as teachers will never be the same after this week."
Bert Waits, April 1995

Bert Waits was speaking to a group of mathematics teachers at a recent meeting of the National Council of Teachers of Mathematics as he referred to the unveiling of the latest in a recent outpouring of new school calculators, now more appropriately called hand-held computers. Manufacturers of calculators and computers have increasingly embraced the educational market as a lucrative and important investment in the future. At the same time, creative teachers and mathematics curriculum developers have increasingly embraced these powerful tools as a critical component of standards-based reform. For several years, computers have offered exciting possibilities for mathematics instruction, but the evolution toward smaller, more powerful hand-held units now makes even more advanced technology available to every student.

Some teachers recognize the truth in the leading quote above, and they seize the opportunity to rethink what and how they teach. Others may agree that their teaching lives are changing, but they may feel inadequate, afraid, or uncertain about what to do. Still others actively ignore the potential of emerging technologies, pretending that these tools were never invented and apparently hoping their students won't find out differently. Teachers at all places on this continuum need support and assistance in improving mathematics teaching and learning. Policy makers, administrators, supervisors, and teacher-leaders have a responsibility to:

- Provide support, equipment, and professional development for teachers who recognize the opportunities inherent in new hand-held technology,
- Provide support and facilitate awareness and planning for teachers who are uncertain about what the technology can and should influence, and
- Provide support, facilitate awareness, and influence policy and schoolwide decision-making to help bring even the most reluctant teacher closer to a willingness to shift teaching practice using technology.

Only with these kinds of support for all teachers at all places on the change continuum can all students experience the kind of mathematics that technology allows.

Technology alone does not solve the problems in school mathematics today. In fact, many schools that have selected self-contained computer learning systems touted as a cure for the ills afflicting today's schools have later found that such systems cannot replace fundamental changes in what we teach and how we teach it. Such programs are only as good as the quality of content

and thinking they contain and the quality of classroom teaching that accompanies them. Even the most exciting hand-held computers now available in mathematics and science have as much power to disrupt mathematics teaching as they do to improve it. The key, as in all school reform, lies with the professional teacher as an instructional decision maker.

What appropriate technology such as hand-held computers can do is to present mathematics educators with both opportunities and responsibilities. The primary opportunity is that of allowing access to sophisticated and challenging mathematics and science for every student, regardless of the student's past mastery of arithmetic or rote skills. The broader opportunity is to rethink our overall notion of what is important in mathematics. With such powerful and potentially accessible tools, we are able to shift the focus of school mathematics to using mathematics to model and solve problems or investigate complex phenomena.

In terms of responsibilities, the overriding responsibility is to ensure that these technological tools are used equitably for all students. Additionally, we have a responsibility to redefine the mathematics curriculum and restructure mathematics classes to make use of the potential of the tools so that all students will be well prepared for the complex world that awaits them after high school or post secondary education. A very real danger is that technology can be viewed as just one more quick fix - as a way to deliver bad curriculum more efficiently. If we do not support the provision of technological tools with comprehensive professional development, curriculum reform, and ongoing teacher support, our critics will be correct to condemn educators for dumbing down mathematics through the provision of calculators. The incredible opportunities possible can be easily lost if these responsibilities are not taken seriously. The relationship is clear:

- We want more students to succeed in high level mathematics.
    - We must therefore change what and how we teach it.
        - Hand-held technology is critical to make the necessary changes.

Seven major focal points capture the opportunities and responsibilities inherent in using technology to improve access to mathematics and science:

1. Mathematics-specific technology
2. Schools' responsibility
3. Teachers as professional decision makers
4. Technology as an access tool
5. Assessment and technology
6. Public partners
7. Potential dangers

1. School mathematics calls for particular technologies unique to the discipline of mathematics.

Technology manufacturers continue to develop increasingly sophisticated hand-held computers that perform sophisticated mathematical functions. Some of these computers, including the wide range of graphing calculators, are designed especially for use by students, and they provide the

same capabilities currently found on desk-top computers with state of the art mathematics software. These tools now perform most of the mathematical procedures that have typically comprised the school mathematics curriculum, including calculating with whole numbers/decimals/fractions, graphing equations and inequalities, solving equations, factoring polynomials, and constructing and manipulating geometric figures, just to name a few highlights. Some of these computers sport dynamic color displays, movable cursors, computer-style keyboards, cable links to scientific experimental probes and desktop computers, and connections to printers. These represent just some of the capabilities of hand-held computers at the time of this writing in 1995; future advances lie only in our imaginations and in science fiction, perhaps even beyond.

Technology such as that described above is absolutely necessary in order to move mathematics teaching and learning in the directions described in the National Council of Teachers of Mathematics standards and other descriptions and guidelines about the reform of school mathematics (see References). This technology can also reinforce the connections between mathematics and related disciplines if such tools are available to students as they work in other subject areas such as science and social studies. Unfortunately, many efforts to infuse technology into schools have either ignored calculators and hand-held computers or have greatly underestimated the need for these tools to be in the hands of every student all the time. Many such efforts focus on computers as the first line of technology access, even though hand-held tools are orders of magnitude more affordable and more relevant for mathematics instruction.

It is quickly becoming impossible to ignore the existence of these tools. Calculators and hand-held computers are now the primary technological tools that should be in the hands of every student. At the elementary grades, school calculators that perform arithmetic calculations, demonstrate number patterns and show integer division with remainders to allow every student to wrestle with good problems from mathematics, from other disciplines, and from the world outside of school. At the upper elementary grades, additional fraction capability allows the exploration of important concepts related to fractions and ratios. As early as the middle school grades, students can benefit from newly designed middle school calculators that perform basic graphing functions and allow the use of tables to explore relationships in data. More advanced graphing calculators should be available as students begin their formal study of algebra, and certainly for all mathematics beyond first-year algebra, a hand-held computer that allows graphing, advanced symbol manipulation and geometric constructions allows students to use algebra and geometry to model situations and solve problems.

Mathematics educators at all levels must call on colleagues in the communities of technology, administration, and other content areas to work together in prioritizing this particular kind of technology as essential when technology funds are allocated. The danger is that when groups of teachers or decision-makers make choices without adequate information about particular mathematics needs, these items tend to get bumped until after computer labs or telephone lines are addressed. As necessary as these latter items are, calculators and hand-held computers designed for arithmetic, algebra, geometry, and advanced mathematics are even more important, since dependent on them are shifts in the very content of the mathematics we teach and opportunities for opening access to mathematics to more students.

2. Schools have a responsibility to provide every student with access to appropriate technology.

Students come from many different economic backgrounds in terms of their ability or likelihood to purchase calculators. Since the cost of various calculators can run from just a few dollars to over one hundred dollars, these differing capabilities set up a situation where we can see a rapidly increasing and dangerous gap between students who are economically advantaged and students who are not. Having an appropriate calculator or hand-held computer cannot be left to chance or to family circumstance.

The responsibility for providing every student with an appropriate calculator that the student can take home, perhaps checked out like a textbook, must lie with the school or the school district. This can be an expensive undertaking. While a classroom set of hand-held computers for every teacher is a start, it cannot be viewed as fully meeting the needs. Some provision for students to take home calculators should be made if these tools are to be equitably available for every student.

Many schools have used PTA funds, federal categorical funds, or grants to provide some of this technology, but this kind of supplemental funding should not be viewed as the primary avenue for purchasing hand-held computers. It is time for a fundamental shift in thinking, so that mathematics is no longer viewed as the *cheap* subject to teach. Where other subjects have typically called for expenditures on maps, globes, science equipment, athletic equipment, or art supplies, mathematics traditionally has required little more than textbooks and chalk. Even the recent trend to provide mathematics manipulative materials has required a relatively small one-time expenditure. Today we are facing a situation where a long-term plan for purchasing hand-held computers might be planned for three to five years, only to repeat itself as technology becomes obsolete. If taught appropriately, mathematics is now one of the most expensive subjects to teach. Prices may fall somewhat in the future, but the fact that something must be provided for every single student makes the overall expenditure considerable. Again, it is important to work with colleagues outside of mathematics to prioritize this expenditure, recognizing that the benefits may overflow into other subject areas and overall development of mathematical thinking.

There is both good news and bad news about this responsibility of schools. The good news is that the cost of supplying a classroom with hand-held computers is a small fraction of the cost of equipping a classroom with desktop computers. In fact, for the price of one single desktop computer a teacher could have a classroom set of even the most sophisticated hand-held computers available. The bad news is that in order to optimize the benefits in terms of learning, every student needs ready access to these tools at all times, not just as a classroom set available during class time. Without such access, those students whose parents can afford it will have access to technology for homework, classwork in other subjects, and informal exploration outside of class. Other students will continue to fall behind in their opportunities for developing mathematical thinking, reasoning, and problem solving, simply because they lack the necessary tools.

Just as schools have a responsibility to provide students with technology, students do indeed have a responsibility to take care of that technology. Many schools have devised successful strategies for managing classroom sets of calculators including simple strategies like numbering calculators and having students always use the same number throughout the year. Monitoring damage or loss when calculators are checked out is somewhat more challenging, but this is an appropriate issue for teachers, supervisors, students and others to discuss locally as responsible professionals. Exchanging ideas across schools can help as educators face these new challenges.

The bottom line is that schools have a responsibility to make good technology decisions for all students. They have a responsibility to ensure that technology is used in the same way in poor communities as in affluent communities. They have a responsibility to use the power of technology to prepare students for high level jobs, not low level ones. And they have the responsibility to accomplish ambitious goals, both in terms of equity and in terms of powerful mathematics, by making sure that every student has access to appropriate technology inside and outside of the classroom.

3. In order for technology to benefit mathematics learning, teachers must serve as highly knowledgeable decision makers - shifting the content of the mathematics they teach, changing their instructional approach, and carefully choosing when and how technology is used.

Directions of reform/change in mathematics are well described in the NCTM standards and a variety of current documents (see References). There is substantial agreement within the mathematics community about several shifts in mathematics teaching and learning, including:

- more emphasis on relating mathematics to life outside of school,
- more development of complex high-level thinking skills,
- more student experience solving problems,
- more involvement in extended tasks and in-depth investigations,
- more use of language in developing and communicating mathematical understanding,
- more focus on big ideas and unifying concepts in mathematics,
- more connections of mathematics to other content areas, and
- less emphasis on extended low-level procedures.

Without these shifts in teaching and mathematics content, technology merely replaces rote pencil-and-paper skills with rote button-pushing. Without the wise use of technology, these shifts are possible in only limited ways with only a limited number of students. Both the changes in teaching and the wise use of technology are necessary together in order for any and all students to benefit from mathematics reform. In order for teachers to make such shifts, accompanying policy changes in curriculum are necessary, but the teacher will likely continue to determine what content is actually taught in a classroom. Knowledgeable teachers must also play the key role determining how and when technology should be used within a comprehensive mathematics program.

Most teachers have neither experienced this kind of learning as students, nor have they learned how to teach in these ways as teachers. In order for them to implement these changes, most

teachers need extensive and ongoing professional development. Such professional development is essential. If teachers are to be equipped to make critical decisions regarding how and when to use technology, they must have an extensive and current knowledge of mathematics, they must have a broad repertoire of teaching strategies, and they must have an in-depth understanding of how students learn and remember. An investment in teacher professional development should rank high on the list of technology priorities. The quality of teacher decisions and the quality of students' experiences in mathematics are ultimately dependent on the quality and nature of professional development that teachers experience.

4. If used appropriately, technology can provide access to high-level, challenging mathematics for every student.

Before the arrival of sophisticated hand-held technology, it used to be necessary for students to master arithmetic skills and rote procedures if they were to be able to deal with more complex word problems or, more broadly, with algebra and geometry. Without proficiency in these low level skills and procedures, students were unable to follow through to the solution of such problems. These skills were not *prerequisites* to higher level problem solving skills, but rather, they were a necessary tool in performing the calculations needed in those problems. There continues to be a dramatic lack of evidence that proficiency in low level skills is in any way related to ability to do high level mathematical thinking or problem solving. We now have no reason to withhold these higher level experiences -*the good stuff* - from students who have not fully mastered low level skills and procedures. We may continue to work on what students don't know while allowing them access to the engaging, relevant, important mathematics that is rapidly becoming the focus of school mathematics.

The potential is immense that more students can deal with more complex problems if they have the availability of a tool that can perform some of the skills and procedures necessary in solving problems. Today, even students who have been marginally successful in arithmetic can develop their abilities to think algebraically and solve high level problems. They can explore patterns, predict outcomes, make generalizations, represent situations algebraically, numerically, or geometrically, and solve interesting, extended, complex problems. This is only possible, however, with the kinds of shifts in mathematics content and pedagogy described in #3 above. The focus of instruction can become the development of these high level understandings, rather than the practice of low level skills. It becomes even more important than ever for students to be able to estimate, use number sense, know when to use which operation, understand how to use the language of mathematics to represent problems, and use a variety of problem solving approaches. It also becomes even more important than ever for knowledgeable teachers to determine the appropriate use of technological tools in providing access to mathematics for every student.

5. Accountability systems must keep pace with instructional uses of technology.

An insidious equity argument has begun to surface regarding the use of hand-held computers on large-scale assessments that are part of accountability systems. Some policy makers and test developers have resisted the incorporation of calculator use on such assessments. They allege that if calculators were allowed to be used on their assessments, some students might be

disadvantaged if they had not used such calculators in their mathematics classrooms. This argument often is the front-line attack, masking more complex issues related to the use of technology in assessment. On closer examination there may be very real concerns about the cost and logistical difficulty of administering a test on which calculators are allowed, there may be confusion over what kinds of questions to ask if calculators are used, and there is likely continuing concern over long standing assessment criteria such as validity and reliability. Instructional leaders should not be distracted by these issues. Professional educators working in conjunction with test developers and test administrators can find solutions to all of these administrative issues, and many are already doing just that in the interest of instruction. Of more importance, giving in to these concerns by not allowing the use of technology on tests presents an even greater equity dilemma - students may continue to be denied access to mathematics simply because of the decision to keep the accountability system static.

The dangers related to technology and assessment are at least two-fold. First, educators may choose to spend precious technology dollars on expensive drill-and-practice computer systems if they believe that low-level skills and procedures are the focus of their accountability system. At the same time, test developers may choose to limit their tests to the kinds of mathematics traditionally taught, thus ensuring that teachers continue to teach in traditional ways, often without any use of even the most basic calculator.

Many schools and teachers are reluctant to make the changes called for today if they believe their students will be measured on something else. As long as high-stakes assessments continue to disallow calculator use, the majority of teachers will continue to put off implementing the use of these calculators in their classrooms. Conversely, when calculator use is called for on such assessments, as in the Texas Algebra End-Of-Course examination, teachers have high-level policy backup for equipping their classrooms with technology and shifting their teaching approach accordingly. Further, in many comparative assessments, such as the National Assessment of Educational Progress (NAEP), the Scholastic Aptitude Test (SAT), the College Board's Advanced Placement tests, and the Third International Mathematics and Science Study (TIMSS), to name a few, students are now expected to use graphing and other calculators to answer complex problems. All of these tests provide rankings of students - individually, by district, by state, or nationally. Ironically, both our highly successful students and those who have not been successful may in fact be disadvantaged by the preclusion of calculators or computers in assessment.

6. In order to accomplish these important and ambitious goals for access to mathematics for all students, we must actively engage parents and the broader public in reforming school mathematics.

Many parents and community members are legitimately concerned that students who are given calculators might learn less mathematics. They worry that the mathematics they were taught will be learned less well if students have calculators to perform the procedures traditionally done with paper and pencil. They may buy into the negative picture painted by the media of schools in general and mathematics performance in particular. They are likely to be even farther removed than teachers from experience or information about the kind of mathematical thinking that is possible if we change how and what we teach.

Working with these parents and other citizens should be part of a comprehensive public engagement strategy that both involves and educates people about the directions of mathematics reform. Parents need to be reassured that we expect students to master multiplication facts, learn basic pencil and paper skills, estimate with numbers, perform mental calculations, and apply what they know to solve real problems. They need to understand that these skills and facts remain important, but that they will not be used as a barrier to hold back students from learning and developing higher level mathematical thinking.

Parents may benefit from participating in mathematics activities conducted by master teachers involving challenging mathematics accessible only with the appropriate use of an appropriate calculator. Family Math programs can integrate appropriate technology use as an integral component of parent activities. As with any systemic effort, making change in how technology is used in mathematics classrooms requires work in many parts of the educational system and its surrounding community.

7. Educators and researchers need to be alert to potential equity dangers in how we use technology in teaching.

As rapidly as technology is advancing, educators are having difficulty keeping up with those advances in how we teach. While there is growing evidence that more students can possibly benefit with the appropriate use of technology in a different kind of mathematics classroom, there is at least as much evidence that simply equipping a classroom with calculators does not in itself ensure equity. Clearly, there must also be a change in content, a change in teaching approach, a change in questions asked and a change in assessment in order to avoid the pitfalls of technology abuse. These changes must be equitably implemented so that students who live in poverty have the same access to exciting technology and challenging mathematics as students who live in affluence.

We must certainly be on the lookout for potential unseen inequities as we continue to develop ways to utilize technology within the broader picture of mathematics reform. We must put high on the research agenda the collection of sound data on what we are now learning in classrooms of master teachers using technology well. If problems should arise in equity or in the effectiveness of new techniques, professional mathematics teachers and other educators have an ongoing responsibility to use their best collective thinking to make course corrections toward the goal of mathematical power for every student.

Supporting the change

Schools cannot effectively incorporate these exciting technological tools into the mathematics classroom without extensive teacher professional development and broad-based public support. Adequate professional development is likely to be nearly as expensive and ongoing as supplying and updating the equipment itself, but it is absolutely necessary if teachers are to realize the need, recognize the potential and change their practice. Such extensive professional development may require additional paid teacher contract days or restructured teacher work days. A variety of effective ongoing professional development models should be part of every teacher's career in this rapidly changing world.

Beyond professional development, teachers need additional support to make change in their classroom teaching. In particular, they need support in terms of resources, policy, moral support and time. Resource support is essential as funds are allocated for the purchase of necessary materials and equipment, especially calculators and hand-held computers. Policy shifts are necessary to enable teachers to make changes in their classrooms; at a minimum these policy changes include upgrading accountability systems, resource allocation, and textbook adoption. Moral support can come in the form of recognition for good work or even the simple encouragement of peers working together collaboratively. The most important support outside of professional development, however, is remarkably consistent across teacher groups, and that is the provision of time. Teachers lack adequate time to plan, communicate with parents, talk with their peers, assess appropriately, explore new resources, learn new techniques, and especially time to reflect on and analyze their teaching and their students' learning.

The challenges and responsibilities inherent in making use of new technological tools in mathematics classrooms are substantial. The opportunities, however, make this work some of the most important work that can be done in the reform of school mathematics. Educators are on the brink of a time in which truly restructured schools and improved mathematics teaching can provide long-term benefits for both students and society. We can go either way - opening the doors of a rich repertoire of mathematical thinking and strategies for every student we teach, or closing the door and opening the gap between large classes of students who have and have not and who can and cannot. The investment to do this work is expensive in terms of time, money, and commitment, but the cost to not do the work is much too high and leaves far too many casualties.

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This article available on line at http://www.tenet.edu/teks/math/resources/techaccess.html as of February 2002.