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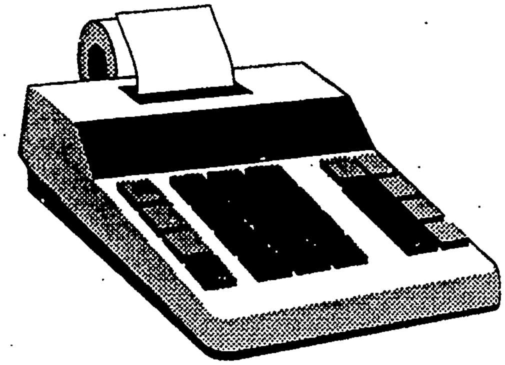
ABSTRACT

This paper begins with cultural and historical perspectives on the use of calculators and then examines a selection of professional writings that the calculator issue has engendered during the period 1976 to 1993. The topics covered are: (1) the calculator in mathematics instruction, (2) the calculator in standardized mathematics assessment, and (3) a sample of research on the calculator in mathematics education. The conclusion includes a discussion of the interrelationship of assessment and instruction in mathematics education. Contains 77 references. (MKR)



CALCULATOR USE IN MATHEMATICS INSTRUCTION AND STANDARDIZED TESTING: AN ADULT EDUCATION INQUIRY

Review of the Literature
1976–1993

by

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INTRODUCTION

In 1911, the first commercial mechanical desk calculator was marketed, followed in 1930 by the first electric calculator from the same company. The first electronic calculator, which included a square root key appeared in 1960. In 1967, Texas Instruments invented the first hand-held electronic calculator, but did not enter the consumer market until 1972 "with the Data-Math Calculator--an 'inexpensive' ($160) four-function, hand-held calculator" (Kenelly, 1989). The rest of the story, as they say, is history. During the past two decades, the hand-held calculator, now available for as low as two percent of its original cost, nearly rivals the television with respect to the degree of integration into American society.

Why, then, has this little machine become such a problem for mathematics education in the United States?

Cultural and Historical Perspectives

There appears to exist in American society a widely-held belief that the successful learning and application of mathematics is the result of innate ability or a gift such as is possessed by accomplished practitioners of the fine arts. Some people are "good at mathematics" and some are not.

A rival hypothesis might argue that the learning of mathematics is an incrementally-developed mechanical process, and that success is related more to drill and practice than to natural aptitude. Those who take the time to learn mathematics, do learn it, and those who don't, don't learn it.

Though the second belief is more optimistic, the prevalent corollary to either one is that mathematics must involve a certain degree of pain, even if one is "gifted." Hoffman (1991) wrote that "mathematics is seen as a test, not only of brains, but of character, of whether someone has the grit to calculate problems day after day, year after year. No wonder people hate it."

Since the calculator represents a way of alleviating a part of the pain, it is regarded by some as a brain–rotting device. But the invention of aids to facilitate mathematics is nearly as old as the practice of mathematics itself.

While the arts were developed in response to the need of humans to express their spirituality, mathematics, on the other hand, had its beginnings firmly rooted in pragmatism. When humankind began to acquire personal (versus communal) property, presumably the idea that "more is better" rapidly became a part of the species' mindset. This trend toward acquisition created the critical problem of how to make sure that one's aggregate of possessions remained intact, for in the earliest societies theft was considered to be a mark of prowess, not an immoral act. Thus, humankind taught itself to count in order to ac–count for its individual stores of wealth. The fingers and toes were capital instruments for setting up one–to–one correspondences; it is no wonder how the decimal system developed. When the need to count greater than twenty arose, other countable objects were employed, the most favored being small stones or pebbles, called "calculi." The use of calculi soon led to systems of "calculation," practiced in various ways and stages by the different developing subsets of humanity. Any method or device that could facilitate a mathematical process was eagerly embraced and utilized.

Next in the progression was the need to measure. Body parts (hands, arms, feet) were used as standards. Rudimentary bookkeeping was developed by the early purveyors of commercial goods. Evidence of the use of algebraic formulas was found in the remnants of both early Egyptian and Indian civilizations. Some mathematical knowledge, such as the use and value of pi, was able tc be carried from culture to culture as humans began to explore their world. With the rise of more advanced and stable civilizations, such as that of the Greeks, mathematical knowledge became systemized. The various inventions, the theorems, the formulas, and the simple machines were passed on through successive generations and became the basis for mathematics even as it is known today. It was truly an evolutionary phenomenon of human intellect, as over time incremental improvements to original ideas and further innovations each building upon one another provided the means by which humankind would attempt to gain mastery over an insecure earthly existence. It was a process which still continues even after many centuries. The point that must be kept in mind is that any proven and useful aid that could make easier the learning and application of mathematics was treasured and preserved and regarded as a stepping-stone to greater heights of achievement.

The earliest known calculating machine was the abacus, thought to have been in use since the year 1000 B.C. It is supposed that the original beads of the abacus were the "calculi" or small stones used for counting. In 1642, Blaise Pascal, the French philosopher and mathematician, at the age of nineteen, built a "computing machine" (Durant, 1963). Pascal's machine was limited to addition, but thirty-one years later, Gottfried Leibnitz of Germany "contrived a computing machine that improved upon Pascal's by performing multiplication and division as well as addition and subtraction (Durant, 1963).

Twentieth century development of the calculator has been noted above. The calculator's prevalence in modern society is undeniable, yet the little machine has proven to be a major bone of contention for mathematics education and its two components, instruction and testing. Instead of taking its place in the long line of welcomed mathematical inventions behind the abacus, the Pythagorean Theorem, logarithm and trigonometric tables and the slide rule, the hand–held calculator has been branded by many in society as an instrument of mental destruction.

REVIEW OF THE LITERATURE

This paper examines a selection of the body of professional writing that the calculator issue has engendered during the period 1976 to 1993. The breakdown of topics is as follows: (I) the calculator in mathematics instruction, (II) the calculator in standardized mathematics assessment; and (III) a sample of research on the calculator in mathematics education.

I. The Calculator in Mathematics Instruction

Use of the calculator in the teaching of mathematics has met with almost universal acceptance by practitioners.

Our age is one of rapid technological change. Most of us, in this country at any rate, have to accept as our destiny the fact that we are factors of production in a major industrial economic power. We live in an era of discontinuous change. We have the option of deviating from these new societal norms, but only if we are willing to accept personal isolation. Most of us are not. Most of us are willing to adapt to the changes that affect our lives.

Many teachers believe that it is vital for mathematics education to follow these social trends, but there has been at the same time resistance to employing new technologies, such as calculators, in the classroom, mainly because calculators have historically not been allowed on standardized tests which attempt to measure the effectiveness of classroom instruction. But many teachers are concerned about the content of the mathematics curriculum itself; they believe it has retained the form of a "saber–tooth curriculum" (Heid, 1988).

In 1954, B.F. Skinner wrote: "We are on the threshold of an exciting and revolutionary period, in which the scientific study of man will be put to work in man's best interest. Education must play its part. It must accept the fact that a sweeping revision of educational practices is possible and inevitable" (Berlin, 1987). Thirty–four years later, Skinner's admonition had not been thoroughly integrated:

> It is 1987. We have probed both far into space and to the depths of the oceans. Technology has enabled humans to walk on the moon several times; it has helped scientists to find the Titanic on the ocean's floor. Many of George Orwell's prophecies have come true, a number of them before the year 1984. Technological advances have made the lives of many citizens easier and more productive. But elementary school students in classrooms across the country still are being taught the long division algorithm using pencil and paper. Why? (Williams, 1987)

The purpose of education is to prepare students to adapt to life in economic reality. That is why "it is inconsistent for us to use calculators daily in our adult lives for personal and business purposes and yet deny students the opportunity to explore the power of this technology" (Kaiser, 1991).

Long division is a case in point, as mentioned by Williams, above. Long division is one of the great traumas of learning mathematics.

> What exactly is the value of long division, or any of the rudimentary arithmetic skills, in the age of the computer and pocket calculator? "What is it we expect students to learn?" asks Thomas Romberg, a professor of curriculum and instruction at the University of Wisconsin at Madison. "If we're preparing them to be Victorian clerks with quill pens and green eyeshades, we're not doing our job. There isn't anyone out there anymore who makes his living doing long division" (Adler, 1991).

The American workplace is an environment which prizes efficiency above all; survival in the market depends upon it. Both the manufacturing and the service sectors must be constantly updating and adjusting to technological innovations. Computers and calculators are now considered necessary equipment and only the most rudimentary of businesses lack them. Computers and calculators offer two crucial advantages over manual systems of any kind: speed and accuracy. People who enter the workforce where the manipulation of numerical data constitutes any part of their jobs must come to work already proficient in the use of computing and calculating machines or they must be trained on the job. Mathematics teachers appreciate the realities of the workplace situation and want to teach a curriculum which will prepare their students adequately for it. In an attempt to give expression to the concerns of mathematics teachers that students need increased emphasis on technology combined with mathematics, Chambers (1989) wrote "we are not seeking better performance on a computation–based curriculum, but better performance on a curriculum better suited to the needs of Americans in the 21st century."

Bell (1978) wrote that there are "concerns about what should remain as 'basic skills' in a computer/calculator age." The majority of mathematics educators will be quick to say that the emphasis in mathematics education should be on developing problem solving skills. Historically, the largest focus of mathematics instruction has been the learning of computational algorithms, or rules for performing computations. In some classroom situations it was found that as much as ninety percent of the time was allocated to computation activities. One commonality found by mathematics teachers is that students of virtually all ages will express dislike (or perceived dislike, at any rate) of "word problems." The reason that people hate word problems is that they simply have not had very much training in, and experience with, them. Most mathematics teachers view calculators as a way to eliminate repeated algorithmic instruction year after year. It should be made clear that those who advocate calculator use in the classroom, even in elementary classrooms, are not saying that computational algorithms should not be taught at all. In fact, they believe that students should be able to perform calculations with paper and pencil, as part of the process of developing what is known as "number sense" or an intuitive feel for manipulating numbers in various kinds of calculations. Prevalent opinion among mathematics teachers indicates the belief that from the primary grades on, calculators should be used for exploratory arithmetic operations and that students should be taught *how* and *when* to use calculators (Mathematics Framework, 1987). What mathematics teachers wish to get away from is the inordinate amount of time spent on practicing computation. Wheatley (1992) wrote that "calculators represent a powerful alternative to the drudgery and inefficiency of paper and pencil arithmetical computation." Mercer (1992) believed that "once we realize what is truly important in mathematics we will be less inclined to stick to our past prejudices about the necessity of training our students to do mechanical tasks." Not using calculators in the classroom seemed to Countryman and Wilson (1991)

> to deny students the opportunity to increase their understanding of mathematics. Our students need time for mathematics: to explore, discuss, describe, interpret, organize, collect, predict, solve. They need the experience of selecting and using appropriate tools and methods. They need practice in applying a variety of mathematical techniques in the solution of real-world problems. They need to use the language and notation of mathematics to express quantitative ideas and spatial relationships. They need practice in constructing valid arguments. Using an inexpensive calculator to enhance their learning of arithmetic will give students more time to develop real mathematical power.

Reys (1989) felt that

> ...the students can concentrate on the concept rather than the tedious computation. Students will still make computational errors, often key–stroking errors, but doing the calculations over again is not a chore... For a teacher, this approach provides the additional time needed to bring meaning to the concept and helps retain students' interest in the concept. A greater variety of examples and different kinds of data can be considered, and more realistic data sets can be examined.

Mathematics teachers have also found that as calculators are increasingly woven into classroom instruction, the process of estimation, and mental arithmetic as well, are both making a comeback within the mathematics curriculum. Wheatley (1992) explained:

> When an individual makes the decision to use a calculator in some way, she or he often performs a thought experiment. In deciding how to carry out certain arithmetical operations, an individual will often construct an anticipated sequence of moves and "run through" the activity mentally before actually entering the numbers.

Estimation of answers has taken on new meaning where calculators have been used for classroom instruction because a student has to have a "ballpark" idea of what the answer to a problem should look like before it pops up on the calculator's display. The student must first distinguish between outrageous answers and answers that fit the general parameters of the problem at hand, and then, must be able to judge how close to the correct answer the calculator's output is. Before calculator use began in classrooms, estimation was only a discrete topic in the sequence of a mathematics textbook; with calculators, it becomes almost second nature.

Some teachers have had success using calculators with students who after eight or nine years of school still cannot perform paper and pencil algorithms, due to learning disabilities or other problems. Many teachers feel that mastery of computational algorithms is not necessarily a prerequisite to moving on to higher forms of mathematics. At some point in children's education, the emphasis given to computation must diminish and problem–solving must become predominant, even if the computational algorithms are not mastered. Many adult basic education teachers also believe that time should not be wasted teaching computational algorithms in their classes because of the students' needs to apply their learning immediately to occupational and personal situations.

The most definitively documented result of calculator use in the classroom appears to be the positive effect on student attitudes toward mathematics in general. Finley (1992) described the changes which took place in her fourth and fifth grade level mathematics class after she decided to integrate calculators into instruction:

> Calculators have been wonderful as a tool for building confidence and self–esteem in students. Students love to be right and to feel that they have the ability to reason something through. The calculator affords them many opportunities to be correct and to receive instant gratification. When they are using paper and pencil and make a computational error, they are more often penalized for the error in computation than praised for correct reasoning. Even if they are praised for their reasoning, the praise is somewhat tainted by the fact that the answer was not exactly right. The calculator helps the teacher in getting the point across that reasoning is the most important step, and it allows the student to feel the great satisfaction that accompanies success.
>
> One especially gratifying incident occurred in that first year of calculator use. I found one of my students, who had a particularly hard time with mathematics, working very intently on a problem and using the calculator to try out his different theories. It was rewarding enough that he had progressed

> to the point of even having a theory and that he was willing to try it out on his own without asking for help first. But my true reward came when he finally approached me, with calculator in hand, and said, "Is this right?" Before I could say a word, he looked at the calculator again and said, "No that's not right. Something is wrong. Let me try again. I think I know what I did wrong." He didn't even wait to hear my response or look up to see the big smile on my face. He was too intent on solving his problem. At the beginning of the year he would have never gotten past the first simple computation using paper and pencil before he would have been totally frustrated and unable or willing to pursue any kind of logic.

Countryman and Wilson (1991) wrote that with calculators their students were "engaged and enthusiastic about the fundamentals of mathematics." Kaiser (1991) reported that "after a few weeks of varied experience using calculators, my [sixth grade] students displayed enthusiasm for calculators and greater facility in mathematics in general" and that "students were eager to come to mathematics class when calculator use was permitted." Reys (1987) asserted that

> the evidence is strong that the use of calculators has many noncognitive benefits. For example, research suggests that students exhibit more enthusiasm and confidence in problem-solving when calculators are available. Students using calculators also have more positive attitudes toward mathematics and demonstrate greater persistence in solving problems [and] are more willing to seek alternative solutions.

Yvon (1987) believed that "students who become mired in drill activities are often prevented from seeing the beauty and enjoying the fun of mathematics" and that "the use of calculators can and will encourage students' creativity in all aspects of mathematics."

A survey of classroom teachers of all grade levels in Missouri conducted in 1979 to investigate attitudes toward calculator use produced the following outcome:

> more than eighty percent of [the teachers] reported observing attitudinal changes in their students. Without exception these changes were positive and were characterized by teacher comments describing students as being eager to attack problems, showing greater confidence in ability to solve mathematics problems, and becoming more excited about doing mathematics (Reys, 1980).

Boling (1977), in a study of twelfth grade consumer mathematics students, reported that "strong positive attitudes toward the use of calculators in the classroom were found."

Opposition to calculator use in mathematics instruction has not been non-existent. The most vocal critic was John Saxon, a textbook publisher. In an article which appeared in the Wall Street Journal on May 16, 1986, Saxon asserted that "students will be unable to do simple computations in their heads, and worst of all they will not be able to estimate." In this same article, Saxon referred to mathematics education in the United States as a "national disaster." A year later, in a professional mathematics education journal, via a paid advertisement, Saxon (1987) wrote that calculator use in elementary schools "will cause great damage to many children, and will provide only marginal benefits to a few" and that "introducing calculators in elementary schools will convince many students that the calculator is a magic box that can be used as a substitute for understanding, and these students will resist the arduous mental effort that is required to develop a feel for numbers and the ability to estimate." Saxon did concede that calculators could be successfully used at the high school level, but only after students have acquired the fundamental concepts of arithmetic.

Marilyn Suydam's (1976–1982) research uncovered some opposition to the use of calculators in mathematics education; these are discussed below in detail (pp.22–23).

Pfeiffenberger's and Zolandz' (1989) survey of pre–college science teachers' attitudes on calculator use included the following negative responses:

–math skills are not learned or [they] atrophy [with calculator use]
–students may simply manipulate the numbers to match a choice instead of solving the problem
–[calculator] use creates a lack of math and analytical skills in students, and thus students don't understand the basic concepts involved.

Usiskin (1975) commented that a popular metaphor used in opposition to calculator use in mathematics education was that the calculators were a "crutch." His response was that

> the crutch premise is seriously open to question, both in its internal validity and in the validity of the conclusions that are reached from it. The crutch premise rests on the principle that a crutch is a bad thing. But in fact, for the injured person a crutch may be a good thing – even a necessity. The capacity for a crutch (bad!) to be relabeled a tool (good!) extends to many situations, and many value judgments may simply depend on which label is perceived as accurate.

Documented opposition to the use of calculators in mathematics instruction has been minuscule when compared with the volume of support positions taken. Especially in recent years, the literature is virtually devoid of negative statements. Higgins' (1990) summation was that "despite the publicity given to arguments about using calculators in the mathematics classroom, I believe that we are devoting time and energy to a nonissue. The real issue is not *whether* calculators should be used in mathematics classrooms; it is *how* they should be used in classrooms."

II. The Calculator in Standardized Mathematics Assessment

One of the initial efforts to move toward calculator use on nationwide standardized tests was the decision of the College Board to permit, but not require, the use of calculators on the Advanced Placement (AP) calculus examinations given during 1983 and 1984. This was carried out on an experimental basis, with the effect that after 1986, the College Board reversed its policy of calculator use on AP examinations due to "the practical problems of administration and the concerns of equity" (Kenelly, 1989).

However, the College Board will once again take the pioneering step of allowing calculators on the Spring 1994 administration of the Scholastic Aptitude Test (SAT) and to phase the policy in, will also permit calculator use on the Preliminary Scholastic Aptitude Test (PSAT) and the National Merit Scholastic Qualifying Test (NMSQT) in the Fall of 1993.

In 1986, a symposium on Calculators in the Standardized Testing of Mathematics was sponsored by the College Board and the Mathematical Association of America. The symposium "endorse[d] the recommendations made by the National Council of Teachers of Mathematics, the Conference Board of Mathematical Sciences, the Mathematical Sciences Education Board and the National Science Board that calculators be used throughout mathematics instruction and testing" (Kenelly, 1989). However, the symposium decided against recommending calculator use on the SAT at that time "because of the importance of the SAT in the college admission process as well as the nature of its mathematical content" (Kenelly, 1989).

During the years 1986–1992, the College Board, in concert with the Educational Testing Service (ETS), which develops and administers the SAT, continued to investigate the feasibility of calculator use on the SAT. What kept the issue alive was the overwhelming support of mathematics educators. From 1987–1989, both the College Board and the ETS conducted studies to determine the effects of calculator use on the SAT. New versions of the SAT were developed in 1991 and field–tested the following year. Rigol (1993) reported that "more than 180,000 students from 2,221 schools throughout the country participated in perhaps the largest field trial of a new test ever administered." In addition to the analysis made from comparing scores of students who were permitted to use calculators on the SAT during the field trials, other kinds of data were solicited from the students pertaining to personal use of calculators, ownership of or access to calculators and students' opinions as to whether calculators should be used on the SAT. Analysis of the score data revealed a slight advantage in using calculators on the test.

The American College Testing (ACT) program is likewise "evaluating the role of calculators in its mathematics tests and is currently studying the impact of calculators on examinees' performance" (Noble, 1992).

Individual state testing programs have also begun to incorporate calculator use on mathematics assessment instruments. In Connecticut, in 1984, the state department of education began developing mastery tests in mathematics to be given in the fourth, sixth, and eighth grades, replacing a single proficiency test administration given in the ninth grade. The calculator issue was present early on in the new test development as a previous (1981) publication of the state department of education had specifically stated that "the widespread availability of calculators cannot be ignored when developing a mathematics curriculum" (Leinwand, 1992). The first test administration was conducted in 1986, with refinements currently being made.

In Michigan in 1986, the state Council of Teachers of Mathematics undertook the preparation of "new mathematics objectives as a model for instructional guidelines" as part of an "overall plan to develop a state test based on the objectives" (Payne, 1992). The Council decided from the start of the project that "calculator use be assumed as integral parts of instruction and testing" (Payne, 1992). As in Connecticut, the Michigan project uncovered the need for revisions to the first run of tests. These complexities, however, do not appear to have been of sufficient magnitude to cause the idea of incorporation of calculator use in state testing programs to be abandoned.

Maroney (1990) listed other state-based standardized tests which permitted calculator use; these include: Missouri Mastery and Achievement Tests, New York State Regents, California Golden State, Ohio Test for Scholastic Achievement, Kentucky Essential Skills Test, and Georgia Test for Teacher Certification in Mathematics.

There are a number of issues concerning calculator use that would apply to any norm-referenced standardized test of mathematics. These include equity concerns, administrative difficulties, and test design problems.

The concern with equity is multi-faceted. One early problem with allowing calculators to be used by students on standardized tests was the realization that not every student owned or had the financial wherewithal to own a calculator. This immediately put the evaluative fairness of tests in doubt; at least, when calculators cannot be used, the playing field itself is level, despite the different socioeconomic levels which comprise the testing population. If the organization which sponsors the test undertakes the investment of purchasing calculators for the test-takers, the concern arises that unfamiliarity with the calculator may even detract from a student's performance on the test. Experimentation with calculator usage on standardized tests (such as the Second Mathematics Assessment conducted by the National Assessment of Educational Progress (NAEP)) in the early 1980's has shown that it is beneficial for students to test with calculators they are familiar with and have used during mathematics instruction.

Another equity problem results from the varying degrees of sophistication among calculators ranging from simple four-function models to non-programmable scientific calculators to programmable graphing calculators. Since the sophistication level of calculators is directly related to their prices, the fairness question once again raises itself. The existence of programmable graphing calculators poses difficulties for the administrators of standardized tests creating the fear that information useful to test questions could possibly be stored and carried out. One suggestion toward resolution of this security problem has been to develop a list of acceptable calculators. The list would be published before the test in application materials and the calculators brought into the test would be checked against the list. This idea has not been eagerly accepted mostly due to the cost in terms of time that would be imposed upon test administration personnel at the test sites. For the ground-breaking 1994 SAT administration, the College Board has decided to allow "virtually any type of calculator" (Rigol, 1993). Both programmable and non-programmable and scientific and graphing calculators will be acceptable; what will not be permitted are any types of computers or calculators with communications capabilities. The present day affordability of hand–held calculators and the prevalence of ownership of calculators by students or their families has largely diffused the equity concerns that were once "paramount" (Rigol, 1991). Also, the mere fact that calculators will be allowed on the SAT should encourage increased classroom usage.

Another issue that standardized testing organizations must grapple with concerns the design of questions on a test where calculators are used to answer the questions. Kenelly (1989) pointed out some complexities of the situation: "psychometricians must certify that the examinations are measuring what they purport to measure" and that "when calculators are used during an examination, testing experts must be certain that the machine's ability to perform mathematics does not interfere with the test's ability to measure the candidate's performance."

Questions fall into three categories: (1) *calculator active* questions which require the use of a calculator to solve them; (2) *calculator inactive* questions which are best solved without a calculator; and (3) *calculator neutral* questions on which the effect of calculator use is undeterminable. Harvey (1989) proposed two definitions that could aid in test development:

> (1) A *calculator–based test item* (a) contains data that can usefully be explored or manipulated by using a calculator and (b) has been designed to facilitate active calculator use.
>
> (2) A *calculator–based mathematics test* (a) tests mathematics objectives, (b) has some calculator–based items, and (c) has no items that could have been

but are not calculator–based, except for items that are better solved with non–calculator–based techniques.

Some proponents of calculator use on standardized testing predict a move away from routine computation and the incorporation of more realistic situation problems with believable data. Others advocate a move away from the prevalent multiple–choice format and into open–ended, exploratory problems, with some even offering a range of answers.

When calculators have been permitted on tests that have not been changed, i.e. when calculator–users and non–calculator–users take the identical test for comparisons of the results, two effects have emerged. One is that computation scores tend to rise – this is no surprise – although there exists the probability that wrong keys will be pressed, and the other effect is that time after time no significant differences have emerged in problem–solving sections of tests when calculators have been permitted and when they were not. It is strongly felt, however, that calculator use on problem–solving test items helps avoid careless errors and that it can help increase the rate at which these problems are solved.

For the 1994 SAT administration, the policy of the College Board is that calculators will be permitted, but that "no questions on the test will require the use of a calculator" (College Board Questions and Answers, 1992). In preparation for 1994, the College Board is advising students "not to try to use your calculator on every question" and "to decide how to solve each problem, then decide whether to use a calculator" (College Board Questions and Answers, 1992).

Another issue is the problem of calculators breaking down during a test. But, if like the 1994 SAT, calculators are not specifically required, there is nothing to prevent the student from successfully completing the test other than an absolute ignorance of pencil and paper procedures. Usiskin (1978) rejects this concern as a problem:

> It is common to cite the case of a real or hypothetical student who takes a calculator into an exam only to have the battery run out, after which the student is helpless and confused. Such events do happen. But when they do, one must ask two questions. First, will the student allow this to happen on the next test? One would expect that a single experience of this kind would suffice and that a similar experience would be avoided. Second, for how many students in the same test was the calculator an asset? In short, one should be careful not to penalize the majority (those with calculators) in a test because of unwise decisions that are bound to be made by a few (those whose batteries run out).
>
> When a computer or business machine breaks down in the real world, few organizations reject the idea of using the machine. Most get it quickly fixed, or they buy a new one. It is a fact of life that machines break down or are at times unavailable, but the increased level of performance that they make possible more than makes up for those inevitable problems.

Finally, the psychosocial impact of the issue of calculator use has been addressed by some writers. "When calculators are banned from tests, students are sent a message about the irrelevance of what they are learning in school to the world outside school" (Wilson, 1989). Heid (1988) wrote that "because calculators are not allowed on most tests, students conclude that the most important part of mathematics is learning to execute computational procedures by hand" and that "students who understood the mathematical concepts and principles could enter testing situations more confident of their ability to produce correct results [using calculators]." According to Reys (1987) "the availability of calculators acts as a control for varying levels of computational skills, serving as an equalizer. The availability of calculators on the noncomputational portions of standardized tests insures that students no longer face double jeopardy – being penalized twice for weak computational skills."

III. A Sample of Research on the Calculator in Mathematics Education

The two most well-known research projects on calculators in mathematics education were undertaken by Marilyn Suydam of Ohio State University and by Ray Hembree of Adrian College and Donald Dessart of the University of Tennessee.

Suydam's work, Electronic Hand Calculators: The Implications for Pre-College Education (1976), was funded by a grant from the National Science Foundation. The report was, as Suydam wrote, "designed to provide [information] on the range of benefits and reactions about calculators, and in particular on the arguments that were being used to support positions strongly favorable and strongly negative toward the use of calculators in elementary and secondary schools."

In her investigation, pursuant to the research design stated above, Suydam collected attitudinal data from educators which expressed (1) support for using calculators in school, and (2) opposition to using calculators in schools. Reasons in favor of calculator use were:

(1) They aid in computation.
(2) They facilitate understanding and concept development.
(3) They lessen the need for memorization.
(4) They help in problem-solving.
(5) They motivate.
(6) They aid in exploring, understanding, and learning algorithmic processes
(7) They encourage discovery, exploration, and creativity.
(8) They exist.

Reasons against calculator use included:

(1) They could be used as substitutes for developing computational skills.
(2) They are not available to all students.
(3) They give a false impression of what mathematics is.
(4) They are faddish.
(5) They lead to maintenance and security problems.

Richard Shumway, who collaborated with Suydam on this report, analyzed the above data which was derived from questionnaire responses and developed what he considered to be the actual arguments for and against the use of calculators in school:

Arguments for using calculators:

(1) There will no longer be any need for the usual paper–and–pencil algorithms for the basic operations.
(2) Scienific calculators will not be expensive.
(3) Extensive drill and practice exercises will be unnecessary.
(4) Decimals and scientific notation will be introduced early in first grade.
(5) Mathematical exercises will be more realistic.
(6) Calculators are fun.
(7) The addition and multiplication algorithms for fractions can be delayed until algebra.
(8) The calculator facilitates number sense.
(9) Handheld calculators make calculations easy and practical for all children.
(10) Handheld calculators stimulate interest in and facilitate the teaching of mathematical concepts.
(11) The calculator can be used to facilitate problem solving.
(12) Handheld calculators provide experience with the only practical algorithm which is used in society today.
(13) Handheld calculators will place the emphasis on when and what operation to use.
(14) There will be more interest in estimation.
(15) The power of mathematics used by the common man [and woman] will increase astronomically.
(16) More time will be available to teach mathematics in depth.
(17) New topics in mathematics can be introduced into the curriculum.

Arguments against using calculators:

(1) Handheld calculators would destroy all motivation for learning the basic facts.
(2) The use of calculators would destroy the basic, mainstream mathematics of the elementary curriculum.
(3) The cost of calculators prohibits their use.
(4) Calculators are particularly inappropiate for slow learners.
(5) The child's notion of the nature of mathematics would be changed.
(6) The use of calculators would reduce children's ability to detect errors...no record of what was done.
(7) Paper-and-pencil algorithms are still necessary, basic skills.
(8) Batteries lose their charge and wear out.
(9) The use of handheld calculators would discourage mathematical thinking.
(10) Parents are unalterably opposed to the use of calculators in the schools.

Suydam reported that in the years prior to 1976 there had been roughly two dozen studies involving calculator instruction, but that many of these were not well designed and that often sample sizes were too small to provide valid inferences and generalizations. Suydam identified only five "transferable findings" which emerged from these studies:

(1) Children can learn to use calculators.
(2) Children generally enjoy using calculators.
(3) Low achievers may profit from using calculators, but calculator use should not be restricted to low achievers.
(4) Calculators can be used for checking paper-and-pencil computation.
(5) Calculators may or may not facilitate particular types of achievement.

Recommendations for needed research were:

(1) when and how to introduce calculators
(2) effective procedures for learning basic facts, computational skills, problem-solving, and various mathematical ideas
(3) effective calculator algorithms
(4) long-range effects of using calculator algorithms
(5) need for paper-and-pencil algorithms
(6) effect of calculator use with specific content and curricula

(7) effect of curricula sequence/emphasis changes
(8) relationship between work with calculators and computers
(9) changes in teacher education curricula
(10) optimal calculator designs

As follow-up to the inital report, Suydam issued five "state-of-the-art reviews" during the years 1978-1982, inclusive. The purpose of these reports was to provide updated information on topics presented in the inital report and to highlight innovations pertaining to calculator use in mathematics instruction. During this time, Suydam also established the Calculator Information Center at the Ohio State University.

State-of-the-Art Review on Calculators: Their Use in Education (1978) reported a wider use of calculators in mathematics education since the inital study in 1976. Suydam indicated that since the first report "the main question has been, "Should or shouldn't they be used on tests?" and even this is fading as an issue: teachers are using tests where calculators, available to all, are neither an aid nor a hindrance in terms of the goals being tested."

Predominant types of calculator uses were identified:

For elementary levels:

(1) checking computational work done with paper and pencil
(2) games, which...provide motivation
(3) calculation
(4) exploratory activities

For secondary levels:

(1) calculation
(2) recreations and games
(3) exploration
(4) use of calculator-specific materials

The Use of Calculators in Pre-College Education: A State-of-the-Art Review (1979) reported growing use of calculators in schools, even to the extent of competency with calculators being included on minimal requirements for graduation in some school districts. Suydam again brought up the testing question in this report:

> Another continuing concern is with the rôle of calculators on tests. In several other countries, calculator use has been allowed on standardized tests; this is not yet true in the U.S. There is a stalemate at present: it is not appropriate to use calculators on normed tests, since both tests and norms were developed without calculators being used. On the other hand, tests which allow the use of calculators will not be available until calculators are in much wider use.

Also highlighted in this review was the research topic of whether or not calculators in instruction were harmful to students' mathematical achievement as measured on standardized testing instruments. Suydam reported that the current studies were indicating no harmful effects resulting from the use of calculators in mathematics instruction, but that there were some limitations associated with the studies.

The Use of Calculators in Pre-College Education: Third Annual State-of-the-Art Review (1980) continued to address the issue of the relationship of calculators in instruction and achievement test scores. Suydam wrote:

> Data from the many studies (studies on achievement which comprise about two-thirds of all [calculator] studies reported) still seeking an answer to the question "Does use of calculators hurt achievement scores?", continue to support the fact that students who use calculators for instruction achieve at least as high or higher scores than students not using calculators, even though the calculator is not used on the test.

This review reported some results of surveys on beliefs and attitudes held by both educators and laypersons regarding different types of calculator uses. Seventy percent of teachers representing instruction at all grade levels were receptive to having calculators available to students. Suydam reported that "teachers generally agreed that slow students or senior high students who had never learned to compute should use a calculator because they would probably never be able to compute otherwise."

The Use of Calculators in Pre-College Education: Fourth Annual State-of-the-Art Review (1981) reported on a development which had taken place since the last yearly report: the overshadowing of the great calculator debate by the introduction of the microcomputer into instructional settings.

Research which focused on problem-solving with calculators produced the following findings:

(1) calculators are useful for problem-solving if the problems are within the range of students' paper-and-pencil computational ability.
(2) students are less afraid to tackle difficult problems when using calculators.
(3) students use more varied problem-solving strategies when using calculators.
(4) there is no significant difference in the number of problems completed with or without calculators.
(5) the use of calculators probably does not affect problem-solving scores significantly.

Suydam's final review The Use of Calculators in Pre-College Education: Fifth Annual State-of-the-Art Review (1982) reported that although fears about calculator instruction had diminished, they "have not redirected the elementary curriculum, as once expected." However, it had appeared that by 1982, approximately one hundred fifty studies pertaining to calculators had been done. Of the seventy-five studies on comparisons of student achievement, with and without the use of calculators, "thirty-five percent evidence that students score higher when calculators are used, forty-four percent indicate there is no significant difference, and only three percent report that using calculators resulted in lower scores than using pencil and paper."

Suydam also addressed changes in attitudes of parents and teachers which occurred since her inital study in 1976. She reported that some twenty-seven surveys had shown an increase in the level of acceptance of calculators. She also pointed out that "teachers' attitudes became increasingly positive after [calculator] workshops or other inservice work."

In a doctoral dissertation (1984) which became well known in calculator research, Ray Hembree, under the supervision of Donald Dessart, performed a meta-analysis integration of seventy-nine research reports for the purpose of assessing the effects of calculators on student achievement and attitude. The research was focused on the effects of calculator use compared with non-use on the acquisition of composite operational skills, productivity, selectivity, problem-solving skills, and attitudes toward mathematics. An additional "observational" research question was also included: "Is special calculator instruction better or worse than instruction within a traditional format without calculators?" The research was conducted with students in grades K through 12.

With respect to operational skills, the findings showed that "...the paper and pencil skills of low and high ability students who received a calculator treatment remained at par with those of the control group. For students of average ability, paper and pencil skills significantly improved after a calculator treatment, except in Grade 4, where paper and pencil skills were hampered by calculator treatment."

Regarding problem–solving skills, Hembree and Dessart found that "low and high ability students neither gained nor lost from the calculator treatment, but the paper–and–pencil skills of average students were significantly improved, though less in Grades 4 and 7 than at other grade levels."

Analysis of the attitude variable revealed that "significant positive effects were found for attitude toward mathematics and self–concept in mathematics."

Conclusions of the research project included the following:

(1) ...a use of calculators can *improve* the average student's basic skills with paper and pencil, both in basic operations and in problem–solving.
(2) the use of calculators in testing produces much higher achievement scores than paper and pencil effects, both in basic operations and in problem–solving. The overall better performance in problem–solving appears to be a result of improved computation and process selection.

Among recommendations regarding classroom usage were:

(1) calculators should be used in all mathematics classes of Grades K–12.
(2) students in Grade 5 and above should be permitted to use calculators in all problem–solving activities, including testing situations. This recommendation is based on these two observations:
    a. calculators greatly benefit student achievement in problem–solving, especially for low and high ability students.
    b. positive attitudes related to the use of calculators may help to relieve students' traditional dislike of word problems.

Hembree and Dessart (1992) extended their original meta–analysis with nine additional studies of calculator usage and student achievement. The new data was found to either support or enhance previous findings. The new data showed that when students are allowed to use calculators on tests that measure achievement, there was:

(1) continued advantage from calculators in computation; and
(2) better advantage from the devices in problem–solving.

Two other research reports, both published by the College Board, have also provided valuable information on aspects of calculator usage.

Surveys of the Use of Hand Calculators and Microcomputers in College Preparatory and College Science Classes by G. Will Pfeiffenberger and Ann Marie Zolandz (1989) was designed to investigate the attitudes and beliefs held by secondary school and post–secondary school science faculty towards calculator use in physics, chemistry, biology, and other science courses. At the time of this research project, the College Board was seeking educator input as standardized test calculator policies were being considered.

Pertinent survey questions and responses are summarized below:

Question 1: This question asked teachers to indicate the uses of calculators in their courses.

Most of the physics teachers who responded...permitted [calculator] use for all types of course work and tests.

The result for chemistry was similar to that of physics. Most of the chemistry teachers who responded permitted [calculator] use for all course work and tests.

The percentage of biology teachers who allowed simple calculators on course work was sixty to sixty–seven percent. Forty–six percent of biology teachers who responded to this question said they allowed scientific calculators to be used on all tests.

Question 2: Do you have any concern about the use of calculators on standardized tests in general?

The main concerns were: students who bring information to the test in programmable memories, the equity issue (both availability and uniformity), dependence on calculator use, and the nonmastery or deterioration of skills. Some also indicated they thought calculators should be allowed on science tests (sometimes with the qualification that the concerns mentioned above be remedied), but should not be allowed on mathematics tests, which attempt to assess the skills that calculator use would replace. Some of the comments favorable to calculator use included:

(1) Failure to use calculators is to live in the 19th century.
(2) I don't see any value in making students do calculation on exams. Knowing how to set up problems is more important.
(3) Slide rule, calculator, what's the difference as long as the student's brain does the programming?
(4) If a student is merely a number puncher, he won't get the right answers anyway. In this day and time, intelligent use of a calculator is a necessary skill.

Another study undertaken by the Educational Testing Service to investigate the feasibility of changes to the SAT, Calculator Survey Report: The Use of Calculators in Urban and Rural Schools (1992) by Jane Marie Maroney, focused on the following points related to the equity issue:

(1) the types of activities (e.g., homework, tests) for which calculator use is permitted
(2) the degree to which college–bound students in urban and rural districts have access to and make use of calculators
(3) the likely impact of using a calculator on test performance and on school policy.

Three groups were designated to participate in the survey: Group 1 – a random sample of six hundred rural and urban school administrators; Group 2 – five high schools each from ten major urban school districts; and Group 3 – the fourteen members of The Urban Mathematics Collaboratives which are located in major urban areas and which are dedicated to developing professionalism of mathematics teachers.

The results of the project included the following:

(1) In response to the question which asked about current school policy on the use of hand–held calculators in mathematics classes, over seventy percent of Group 1 indicated that their policy permitted the use of a calculator on homework and classwork. However, in the area of testing the response was more conservative.
(2) The type of calculator thought to be the most appropriate for use on the SAT was a non–programmable scientific calculator.
(3) In response to the question which asked about the percentage of college–bound students that own or have regular access to calculators, over eighty percent of the respondents indicated that seventy–five percent of their students do own or have access to calculators.
(4) The majority of urban and rural schools indicated that ninety percent or more of their students are able to use calculators for the basic operations.
(5) Fewer than one–third of the respondents reported any concerns if the use of calculators were to be permitted on the SAT.

The researcher concluded that most educators favor the use of calculators on the SAT.

CONCLUSION

The Interrelationship of Assessment and Instruction in Mathematics Education

According to Kenelly (1989), "standardized tests have achieved importance because they give independent benchmarks of educational achievement." One would assume that the writers of such tests take into account the vast body of knowledge being transmitted from teachers to students in the nation's schools, attempt to identify commonalities in that knowledge, and develop questions to check students' retention of and ability to apply that knowledge. However, the purveyors of the knowledge, the teachers and administrators, have a vested interest in the satisfactory performance of their students on such testing instruments. Therefore, a circular situation occurs such that testing follows instruction (for the purpose of constructing the test) and instruction follows testing (to ensure good performances by students). This is a schematic into which a "new" innovation like the hand–held calculator does not easily fit because to change one side of the equation requires a change of equal magnitude on the other side. Because the institutional structures for testing and instruction are discrete as well as diverse, it is difficult for change to occur.

The instructional side of the mathematics education coin was the first to deviate from the cycle by allowing calculators into the classroom for some limited usages. Ostensibly, this occurred as a result of the early, positive endorsement of classroom calculator use, by such organizations as the National Advisory Committee on Mathematics Education (NACOME) and the Association of State Supervisors of Mathematics.

As far back as 1975, NACOME recommended "that beginning no later than the end of the eighth grade, a calculator should be available for each mathematics student during each mathematics class. Each student should be permitted to use the calculator during all of his or her mathematical work including tests" (Keys, 1980).

In the National Council of Teachers of Mathematics (NCTM)'s 1980 publication An Agenda for Action: Recommendations for School Mathematics of the 1980's, one of the eight recommendations stated that "mathematics programs must take full advantage of the power of calculators and computers" (Lilly, 1987). In 1986, the NCTM's Board of Directors recommended that all students use calculators to:

-concentrate on the problem-solving process rather than on the calculations associated with problems;
-gain access to mathematics beyond the student's level of computational skills;
-explore, develop, and reinforce concepts including estimation, computation, approximation and properties;
-experiment with mathematics ideas and discover patterns, and perform those tedious computations that arise when working with real data in problem-solving situations (Harvey, 1991).

In 1989, the NCTM published Curriculum and Evaluation Standards for School Mathematics, its developers having been charged with the task of "creat[ing] a coherent vision of what it means to be mathematically literate both in a world that relies on calculators and computers to carry out mathematical procedures." (NCTM Working Groups, 1989).

The Association of State Supervisors of Mathematics issued a position statement in 1990 which included: "mathematics instruction should exploit the power and convenience of calculators and computers and the circumstances of testing should be compatible with the circumstances of instruction" (Position Statement, 1992).

Still, without official sanctioning by standardized tests, calculators have been slow to achieve complete integration into classrooms. While mathematics education professionals expressed the need for the development of materials written specifically for use with calculators, few materials of this kind were marketed. Textbook writers acknowledged the existence of calculators by providing a few supplementary exercises at the ends of problem sets. Carter (1987) felt that this situation signified a "curricular imbalance." Others worried that the implicit message being sent to students was that there was a lack of connection between education and real-world experience. Suydam (1979) expressed the situation as a "stalemate" pointing out the inappropriateness of using calculators on normed tests, "since both tests and norms were developed without calculators being used. On the other hand, tests which allow the use of calculators will not be available until calculators are in much wider use."

As noted above, the stalemate has now been broken as a result of the College Board's initiative. Many state-based examinations permit calculator use, and the ACT program is seriously reviewing the issue.

Epilogue

This review of the literature on calculators in mathematics education was undertaken as the first step in an inquiry to determine the feasibility of using calculators on the national, standardized General Educational Development (GED) examination.

A literature search revealed no published articles on calculator use on the GED examination and only eight applicable articles dealing with calculator use on standardized tests in general. These articles were primarily concerned with the development of a calculator policy for the SAT and one addressed a similar ongoing process for the ACT examination. Most of the professional writing on calculator use in mathematics education was related to mathematics instruction in Grades K–12, as examined above.

What implications, then, does the extant research on calculator use have for adult education and the GED examination?

Successful passage of the GED examination is supposed to indicate acquisition of a body of knowledge possessed by seventy percent of high school seniors in the United States. (This percentage indicates what proportion of high school seniors can pass the GED examination). The GED examination, like other standardized tests, undergoes revisions as part of the norm–referencing process, to ensure currency with the high school curriculum. As elementary and middle school curricula are the foundation for high school, then instructional practices and innovations therein would most certainly have an impact on the nature of the high school curricula, and therefore, on the GED examination. If, in fact, as the literature overwhelmingly appears to indicate, calculators are being integrated into curricula at all levels and will now also be permitted on the best known pre–college assessment tool, the SAT, the field of adult education and the national GED administration should not delay participation in this inexorable trend. To do so would raise questions about the GED's relevancy to the entire educational spectrum in this country.

In conclusion, three sequential research topics are proposed:

(1) Concurrent surveys of adult education teachers and students pertaining to extent of use of calculators in personal lives and to attitudes concerning calculator use in instruction and testing.
(2) Field trials on calculator use on practice GED examinations, controlling for calculator instruction in GED classes.
(3) Field trials on actual GED examinations.

As adult educators, we have the responsibility, as Heid (1988) expressed it, "to stop preparing students for the past and start preparing them for the future."

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