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ABSTRACT

This document summarizes the research done on calculators and calculator use. It is noted that calculators are now seen as acceptable, with fears about use in school currently infrequent, and the role of such devices much more evident than 6 years ago. The first two sections of this material summarize data on use and availability. It is noted that within the 75 studies used in this analysis, 35% provide evidence that students score higher when calculators are used, 44% indicate no significant difference, 19% report mixed findings, and only 3% report calculator use led to lower student scores. This document next covers problem solving and calculator use in the following content areas: counting, basic facts, addition and subtraction, multiplication and division, decimals, estimation, and trigonometry. Evidence on testing, curriculum concerns, and attitudes conclude the review. (MP)

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The Use of Calculators in Pre-College Education: Fifth Annual State-of-the-Art Review*

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I'll figure my checkbook the old-fashioned way, with pocket calculator and pen.
(excerpt from a letter to the editor, TV Guide, 12-16 June 1982)

The quotation above reflects the way many people now feel about calculators: they are acceptable! The fears about using calculators in schools that were rampant in 1976 are infrequent in 1982. This does not mean that they are used in every classroom, but certainly their use in schools is not the issue it was six years ago. Calculators have not redirected the elementary school curriculum, as once was expected, but activities with them are included in many textbooks. At the secondary school level texts for algebra, trigonometry, and calculus integrate their use. Thus, the role of calculators in mathematics instruction is much more evident than it was six years ago. They are simply too handy a tool to ignore.

Research has provided support for this acceptance of calculators. For the past four years, this annual review has cited research findings on calculator uses which seem applicable to instruction. This fifth review summarizes that research, one of the largest bodies of research on any topic or material in mathematics education. It by no means provides all of the answers on using calculators, but it does indicate some effective practices.

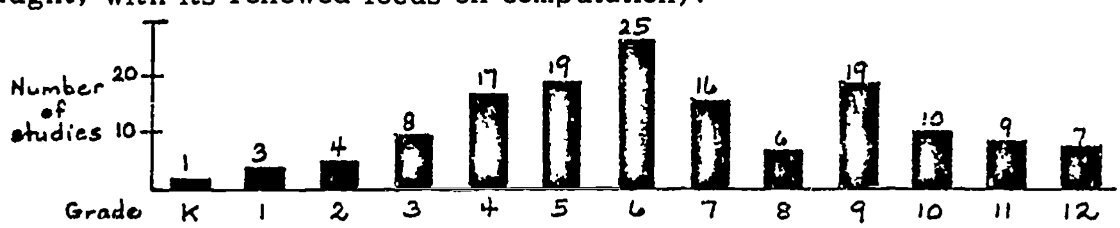
Research studies are often criticized because of weaknesses in design or execution. In this review, no attempt has been made to restate such criticisms. Rather, that which

* Previous annual reviews have appeared in April 1978, May 1979, August 1980, and August 1981.

seems plausible has been abstracted from the research, with generalizations drawn from various studies. This seemed the only feasible way to review approximately 150 studies in this small space. (For a list of the references used, please contact the Center.) The first two sections summarize data on the use and availability of calculators. Then follow sections on the use of calculators for problem solving and a variety of content areas. Evidence on testing, curriculum concerns, and attitudes conclude the review.

Use vs. Non-use of Calculators

In 75 studies, comparisons of the achievement of groups using and not using calculators for instruction on a wide variety of content have been conducted. The studies span all grade levels, with many involving more than one level. The distribution shows peaks at the intermediate grades and in grade 9 (in which general mathematics is commonly taught, with its renewed focus on computation):



The following pattern is indicated by the findings of the 75 studies (with more than one result in some studies):

| C > NC (n = 43) | C = NC (n = 47) | NC > C (n = 5) |

C > NC ---> calculator group scored higher than non-calculator group
C = NC ---> no significant differences between the two groups
NC > C ---> non-calculator group scored higher than calculator group

This differs from the typical outcome of educational research, where the pattern is often: |+| = |−|.

In 19% of the studies, mixed findings (some supporting and some not supporting use of calculators) were reported. Over one-third (35%) of the studies provide evidence that students score higher when calculators are used, 44% indicate there is no significant difference, and only 3% report that using calculators resulted in lower scores than using paper and pencil. Thus, the evidence clearly supports the idea that use of calculators will result in achievement as high or higher than when calculators are not used. The number of studies in which calculator use is not as effective is miniscule in comparison.

Availability and Use

Two points are evident from surveys on the availability and amount of use of calculators: (1) a majority of children own or have access to a calculator, and (2) a minority of teachers use them in the classroom. However, the latest published data on classroom use are from 1977: change has without doubt occurred in the intervening years!

The data indicate that no more than 50% of the students in any school had access to calculators in 1975; by 1979, reports of districts in which 80% to 100% of the students owned or had access to calculators were not unusual. As grade level increases, availability increases. Thus, data from the second National Assessment indicated that 75% of the national sample of 9-year-olds had a calculator available, 80% of 13-year-olds, and 85% of 17-year-olds.

The data on use (from 1977) indicate that calculators were used by less than 20% of elementary teachers and less than 36% of secondary teachers. Only in grade 12 advanced mathematics classes were they used by 60% or more of the teachers.

Problem Solving

Calculators are an effective aid in problem solving, according to a number of studies in which students scored higher when they used calculators to help them solve problems than when they did not use calculators. Researchers have therefore turned their attention to specific ways in which calculators can promote problem-solving skills.

The calculator appears to be useful when the problems to be solved are within the scope of the child's ability to solve them using paper and pencil. If the child does not know how to solve a problem, it does not make much difference whether calculators are used or not. However, if students know what to do or what operation to use, but cannot perform the computation, the use of calculators can result in substantial improvement in problem-solving scores.

The National Assessment results indicate that solving a problem involving a computational example (such as $37 \div 5$) is more difficult than finding the answer to $37 \div 5$ when it is not embedded in a problem. It was concluded that children need to learn strategies for solving problems. Several researchers have explored the belief that calculators will aid children in developing strategies by taking the focus from computation and thus allowing them to focus on the process of solving the problem. This should, it has been hypothesized, help them to learn and apply a broader range of strategies, as well as making particularly viable a guess-and-test strategy.

The evidence differs on the number of problem-solving strategies used when children have calculators. One study with sixth graders found that they used more strategies, while two others reported that they used the same number. It would seem clear that instruction developing strategies must occur in addition to using calculators. Similarly, the evidence differs on whether students using calculators can complete more problems.

No evidence was found that elementary school students become calculator-dependent. Indeed, they did not use calculators when their use was unnecessary or of no particular advantage. However, students were less afraid to attempt difficult problems when they could use calculators.

The calculator is a tool: it will help children solve problems provided they are taught the strategies to use in going about problem solving and the knowledge of how to apply computational skills.

Counting

How early can children work with calculators? The evidence indicates that they can start using calculators when they enter school: calculators can be used as an aid to counting. Most of the children studied in kindergarten and grade 1 could maintain a one-to-one correspondence between an oral count and a calculator count; that is, they could point to an object, say "1", and show "1" on the calculator; point to a second object, say "2", and show "2"; and so on. Kindergarten children were less willing than first graders to rely on the calculator count when there was a discrepancy between the two counts, however.

The calculator can also be used to help children learn ideas such as "counting by 1 is the same as adding 1." Skip counting by 2s, 5s, and other numbers is facilitated, and thus foundations for multiplication are developed.

Basic Facts

Basic facts such as 7 + 9 = 16 or 5 x 4 = 20 are considered by many to be prerequisite to work with calculators, and they are certainly essential for children to learn in order to check their work on calculators. However, children can master basic facts with calculators as well as without calculators. In three studies, no significant differences were found, while in a fourth study those using calculators scored significantly higher than those not using calculators to help them master the facts.

In two cases, use of regular calculators to learn basic facts resulted in higher scores than using preprogrammed "calculators" which provide drill and practice with confirmation of correctness. In another case, the group using paper and pencil scored higher than the group using preprogrammed "calculators." The versatility of the regular calculator (it can be used for far more than just practicing the basic facts) combined with its cost (much less than a preprogrammed "calculator") makes it a realistic choice.

Addition and Subtraction

In work with addition and subtraction, third graders exhibited a high degree of accuracy (94%) when calculators were used. However, they did decidedly less well when they worked with types of mathematical sentences that had not been specifically taught (for example, $\square + 36 = 97$).

As part of a continuing series of investigations, the ideas of "chaining" and the doing/undoing property in addition and subtraction were explored. Children could manipulate the calculator keyboard, but they had difficulty conceptualizing the ideas with which they were working. Thus, some mathematical content cannot be taught, even though the calculator provides a way to perform the computation, until children can understand the concept involved.

Scores on subtraction (with which children have greater difficulty) are more likely to be higher when calculators are used.

Multiplication and Division

While there is no disagreement about the role of multiplication in the curriculum, a serious question has been raised about the amount of time spent on division. In An Agenda for Action: Recommendations for School Mathematics of the 1980s, the National Council of Teachers of Mathematics proposes that work with division include "mental facility with simple basic computations, paper-and-pencil algorithms for simple problems done easily and rapidly, and the use of the calculator for more complex problems" (p. 6).

Somewhat surprisingly, little research has focused specifically on the teaching of either multiplication or division. We do know that students are more accurate when they use calculators for these operations (especially division). And we know that calculators are particularly helpful for low-achieving students when they do division. For example, when low achievers used either calculators or multiplication tables in conjunction with work on division, those using calculators scored higher than those using tables.

It should be remembered that work with manipulative materials, including reinforcement of place value ideas, plus work with estimation, are essentials to work with multiplication and division using calculators.

Decimals

Since with calculators students meet decimals far earlier than once was true, the order of teaching fractions and decimals has been questioned. No significant differences in achievement were found between a decimals-then-fractions sequence and a fractions-then-decimals sequence in one study. In another study, the decimals were introduced with calculators, as an extension of whole number operations, while fractions were presented later. Children using this sequence had significantly higher scores than those taught the usual fractions-then-decimals sequence. Thus, it would appear plausible that decimals can be taught before work on the operations with fractions (confirming earlier studies conducted before the availability of calculators).

In general, no significant differences in achievement have been found between groups using or not using calculators for work on decimals, or, if differences were evident on the posttest, they have evaporated by the time of a retention test a few weeks later.

Estimation

Estimation is considered a vital skill for children to have when they use calculators. They must be able to ascertain whether the answer they obtain from the machine is "within the ballpark" or approximately accurate. However, most studies in which children were taught to estimate with the calculator have reported no significant differences. In one study with programmable calculators, though, it was found that having students write their own programs to verify their estimates was more effective than verifying their estimates with a teacher-designed program or with a hypothetical experiment.

While computational achievement has been positively correlated with the ability to estimate, many students do not use estimation to verify answers, either with or without calculators. Moreover, students are readily willing to accept unreasonable answers from calculators.

Whether or not calculators are used, it seems imperative that students at all levels must be taught estimation skills. Apparently, they must also be taught (1) to mistrust the answers produced by machines and (2) the importance of estimation in order to check on the machine.

Trigonometry

That calculators can be useful in teaching trigonometry is reflected by a number of trigonometry textbooks which integrate the use of calculators. In two studies on trigonometry, one with specially developed materials and one in which students developed their own simple trigonometric tables, no significant differences were found. Perhaps more extensive studies will reflect the benefits of using calculators with this topic.

Testing

In most of the 75 studies in which the use of calculators was compared with non-use, children were not allowed to use calculators on the tests. When this factor was studied specifically, the obvious was found: students using calculators on tests scored significantly higher than students not using calculators on tests. The calculator can compute more accurately and quickly than when paper-and-pencil techniques are used! However, equally obvious is that if only a small portion of the test items are of a type where the calculator can be used to advantage, then no significant differences result.

When the effect of calculator use with a standardized test was studied, scores on the computation subtest increased when calculators were used, as expected. Somewhat unexpectedly, however, completion rates were much lower on both the problem solving and the computation subtests when calculators were available.

In the National Assessment, children also did not always benefit from having calculators available for problem-solving items. However, they did substantially better on computation items when they could use calculators. The most dramatic instance of this is with division, where on one exercise ($28/\overline{3052}$) 9-year-olds scored at the 50% level with calculators, even though most had not yet been taught the division algorithm. For 13-year-olds, the increase was from 46% without calculators to 82% with calculators, while for 17-year-olds the increase was from 50% to 91%. It seems apparent that with calculators students could accurately perform computation they could not do as well (or at all) with paper and pencil.

Handicapped Learners

When students with multiple physical and mental handicaps used calculators, they scored higher, were faster, and attempted more problems. Children who were mentally handicapped learned to operate the calculator with a minimal amount of instruction, although they did have some difficulty with learning to clear the display and use estimation. Blind and partially sighted students were able to use cassette manuals to learn how to operate three types of calculators.

Thus, students with a variety of handicaps can use calculators to aid them in mathematics. Similarly, students with learning disabilities can use calculators to help them overcome some difficulties, both with computing and with the manipulation of symbols on paper.

Curriculum

In 33 studies, special materials were developed for use with calculators, ranging from short units to year-long programs. Where comparisons were made between groups using the specially-developed calculator materials or other materials, achievement was higher for those using the developed materials in about half the cases and not significantly different in about half the cases. Whether the developed materials could have been made more effective in these latter studies was not explored.

When extensive evaluation was done with two calculator-integrated texts for grades 11 and 12, it was concluded that not only did they teach mathematical ideas, but also discovery was implemented as a viable instructional strategy. Moreover, calculators facilitated the interaction between students and teacher; like manipulative materials, they served as a means of helping teacher and learner communicate about mathematical ideas.

Several researchers have analyzed the curriculum, noting particular topics with which calculators could be used most effectively. A number of textbooks integrate the use of calculators with secondary school mathematics, while materials at the elementary school level are usually supplementary in nature. Unfortunately, few of these use the calculator to teach mathematical ideas; most provide practice on computation (which it is obvious the calculator can do). Few stress the coordinated use of manipulative materials, which are known from research to be an important component to the development of mathematical ideas.

Attitudes

Of 36 studies in which the attitudes of groups using and not using calculators were compared, 30 reported no significant differences and 6 reported that attitudes improved when calculators were used. The relatively short period of time in which many studies took place is certainly one factor which accounts for the lack of change in attitudes, combined with the lack of sensitivity of the instruments used to assess attitudes. Attitudes are developed over a long period of time, not shaped and changed by short-term treatments or one new tool. However, attitudes were not found to change over the course of most of the year-long studies, either. Nevertheless, many teachers report that the use of calculators is motivational.

A number of surveys (27 in all) have also been conducted to assess the attitudes of parents and teachers. These indicate that the level of acceptance of calculators has increased since 1976. Both groups are much more accepting of the use of calculators in schools as grade level increases; that is, they are much more willing to use them in intermediate grades than in primary grades, or in secondary school than in elementary school. They continue to be negative about using calculators to replace paper-and-pencil skills, but are rather accepting of their use along with paper-and-pencil work. One national survey indicated that calculators are perceived most favorably for checking answers (by over 84%), with moderate support for using them to develop ideas and concepts, solve word problems, and do homework.

Teachers' attitudes become increasingly positive after workshops or other in-service work. Thus, continuing education is vital in this and in other curricular and instructional changes.

Concluding Comment

In An Agenda for Action, the National Council of Teachers of Mathematics recommends that mathematics programs take "full advantage" of the power of calculators at all grade levels. The research evidence supports the use of calculators at all grade levels, indicating that achievement will not be harmed and may be enhanced when calculators are used. Furthermore, the evidence indicates that some mathematics content is taught better when calculators are used than when they are ignored.

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