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ABSTRACT

The increasing use of microcomputers and hand-held calculators has implications for mathematics and science instruction, achievement testing, and educational research. The potential effects of these technologies on curricula involve both content and delivery. In mathematics instruction, the focus may shift from manipulative to higher order skills. In both science and mathematics, instructional delivery will include the use of computers and calculators to demonstrate concepts, teach through experimentation, and teach through programming. The curricular validity of achievement tests may be threatened--in particular, those administered through the Admissions Testing Program and the Advanced Placement Program of the College Entrance Examination Board. Threats to credibility are linked to the perception that programs that ignore technology are out-of-date, and to the view that tests dictate curricula. Further research is needed to: (1) survey the curricula in high school and first-year college science and mathematics; (2) analyze the content of Advanced Placement and Admissions Testing Program mathematics and science tests in relation to curricular trends; (3) explore the implications of developing new test items versus new tests; (4) assess the implications of allowing the use of calculators during testing; and (5) develop, administer, and analyze a computer based laboratory science test. (Author/GDC)

RM-86-1

RESEARCH MEMORANDUM

IMPLICATIONS OF NEW TECHNOLOGY FOR MATHEMATICS AND SCIENCE TESTING

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Abstract

This report explores the potential effects of microcomputers and hand-held calculators on mathematics and science curricula in secondary school and the first year of college. These potential effects are explored to identify implications for the possible modification of school achievement tests--in particular, those administered through the Admissions Testing Program and the Advanced Placement Program of the College Board--and to develop recommendations for research needed to support such adaptations.

The potential effects of these technologies on curricula are likely to occur in two areas: content and delivery. Calls for change in curricular content appear focused on mathematics where the major effect of technology may be to shift the focus of instruction from manipulative to higher order skills. Modifications in curricular delivery are evident in both mathematics and science. Trends include the use of computers and calculators to (1) demonstrate concepts, (2) teach content through experimentation, and (3) teach content through programming.

The implications of these potential changes for achievement testing include threats to test validity and credibility. Threats to validity arise primarily from the potential mismatch between test and curricular content. Threats to credibility are linked to the perception that programs that ignore technology are out-of-date and to the

view that tests dictate curricula. Research to address these threats is suggested.

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The incorporation of new technology by America's public schools and postsecondary institutions is proceeding at a rate unprecedented in the history of educational change. The leader of this technological blitz, the microcomputer, is rapidly becoming a standard part of the fabric of the school. Witness the spate of recent purchases by large city school districts and state education departments: 2,000 machines a year for the next three years to the Los Angeles Unified School District; 2,000 Apples in 1985 for the San Diego schools; 4,500 systems for the Houston Independent School District; and 24,000 IBM Personal Computers by the West Virginia Department of Education (THE Report, 1985). As of June 1985, some 1.2 million computers were owned by the nation's public schools (THE Report, 1985), with 85% of elementary, 92% of junior high, and 94% of senior high schools represented (Quality Education Data, 1985).

In the nation's colleges and universities the phenomenon is no less apparent. At last count, over 1.5 million units were owned by these institutions (THE Journal, 1984). By the end of the 1985 calendar year, each of the nation's colleges reportedly will have purchased between 100 and 5,000 microcomputers (THE Report, 1985), and by 1987, four million college students will possess computers ("Four million," 1984).

The purchasing explosion within the nation's educational system is being accompanied by important political and attitudinal changes. State education departments are beginning to require students to take courses in computing and to mandate computer training for teacher certification regardless of specialty area (Barbour, 1984). The National Assessment of Educational Progress (NAEP), a report card on the condition of public education in America, will institute a test of computer competence to be given to students in elementary, junior high, and high school (Benderson, 1985; Tucker, 1985). And what of the nation's teachers? The overwhelming majority are said to believe that computers can help them teach more effectively (Riccobono, 1985).

In the colleges, too, policies are changing. Admission to technical programs at such institutions as Carnegie-Mellon, Drexel University, and Stevens Institute of Technology, carries with it the requirement to purchase a personal computer (Educational Testing Service, 1985). Liberal arts schools, led by Clarkson College, are also beginning to follow the trend.

In somewhat less dramatic--and less rapid--fashion, the hand-held calculator also is showing indications of being incorporated in American education. The use of these devices is widely supported by teacher associations (MCTM, 1984; NCTM, undated) and state education departments also have encouraged their use in schools. The California State Department of Education (1985), for instance, suggests that students use calculators routinely in solving problems. The Florida Department of Education (undated) includes in its

Student Performance Standards the requirement that students demonstrate knowledge of calculators as applied to mathematics.

In sum, new technology seems to be taking root across the grounds of American education. This new growth may produce effects ranging from simple physical modifications in the arrangement of the traditional classroom to revolutionary changes in the basic concept of the centralized school. This report explores one small, but important, member of this universe of potential effects: the effect of microcomputers and hand calculators on mathematics and science curricula in secondary schools and in the first year of college. These potential effects are explored to identify implications for the possible modification of school achievement tests--in particular, those administered through the Admissions Testing Program and the Advanced Placement Program of the College Board--and for the research needed to support such adaptations.

Reference material for the report was gathered from several sources. Primary among these sources were the Educational Resources Information Center (ERIC), professional associations, state education departments, education and computing journals, and national commission reports. Software vendors were also contacted to identify programs produced for use in mathematics and science education, and some of these materials were tried out. Finally, to help us locate additional information, formulate ideas, and evaluate those formulations, a small number of high school teachers and professors were interviewed.

In the course of developing this paper, it rapidly became evident that the distinction between microcomputers and some types of calculators is not perfectly clear (Georgia Department of Education, 1981). While the wallet-size, four-function calculator can be readily distinguished from the computer, scientific calculators of the type used in high school and college courses cannot. These hand-held calculators are programmable and models that accept modular packages containing commonly-used computing routines have been on the market for several years. For purposes of this report, then, microcomputers and calculators are differentiated primarily where the distinction between these two technologies is important to their potential curricular effects.

The report is organized in three major sections dealing with the effects of microcomputer and calculator technology on curricula, the implications for achievement testing, and recommendations for research.

Effects of New Technology on Curricula

Calls for changes in the content and delivery of public school mathematics and science curricula are currently widespread. In general, critics feel that students at all levels are not being given the basic scientific literacy needed for college, employment, and citizenship (Romberg, 1984; Mathematical Association of America, 1984; Twentieth

Century Fund Task Force, 1983). Widespread scientific literacy is said to be important to the continued health of the economy and for making informed political decisions about such timely issues as pollution, radiation, and nuclear energy (Twentieth Century Fund Task Force, 1983).

The key to achieving widespread scientific literacy is often stated in terms of teaching students how to solve problems. Students should learn to formulate key questions, analyze and conceptualize problems, define the problem and the goal, discover patterns and similarities, seek out appropriate data, experiment, and then transfer skills and strategies to new situations (NCTM, 1980a). To do this in mathematics at least, critics suggest that more substance and different topics be added to the curriculum (Romberg, 1984).

A second oft-cited component of scientific literacy is technological skills (e.g., NCTM, 1980b). Such skills are considered by some to be among the new "basics." For example, advocates suggest that calculators and computers be introduced into the mathematics classroom at the earliest grade practicable and that calculators be as available to students as textbooks (The Conference Board of the Mathematical Sciences, 1982). In addition, the National Commission on Excellence in Education (1983) has called for at least a half-year of computer science as a high school graduation prerequisite for <u>all</u> students.

Calls for change in mathematics and science curricula appear driven by a set of interrelated social and political conditions that demand increased scientific literacy. Primary among these forces is the need to compete economically with other industrialized nations--especially Japan--and to remain militarily strong. In both these contexts, scientific literacy is seen as critical to productivity and new ideas.

That we are not developing the scientific literacy needed to remain economically and militarily competitive is evidenced by a variety of indicators. In mathematics, for example, 25% of the courses offered at four-year colleges are reportedly remedial, test data from the National Assessment of Educational Progress indicate substantial shortcomings in concept learning and problem-solving, and students spend less time studying the subject at all grades and enroll in fewer courses than their Japanese counterparts (Romberg, 1984).

A second, and related, driving force is the technological revolution engulfing the industrialized world. New technology is ubiquitous: consumers find microcomputer control systems in 35mm cameras, microwave ovens, videocassette recorders, home thermostats, and automobiles. In the work place, the microcomputer is used for a host of purposes including word processing, manufacturing control and design, data management and analysis, and electronic mail. Schools must prepare students to live in a world in which more and more functions are being performed by computers (NCTM, 1980a).

A third driving force is the educational potential of the technology itself. This potential is in part owed to the importance of the technology as a subject of instruction, but also lies in technology as an instructional adjunct (Bennett, in press). At elementary, secondary, and college levels, research has generally favored the effectiveness of computers as supplem' ' to instruction. Studies have found students to learn more, require less time for learning, and show more positive attitudes toward coursework when computers are used to help deliver instruction (Kulik, Bangert, & Williams, 1983; Kulik, Kulik, & Cohen, 1980; Murphy & Appel, 1984; Ragosta, 1983).

These various interdependent forces have resulted in calls for curricular change in two basic areas: ontent and delivery. We now turn to a discussion of the potential effects of microcomputer and calculator technology in each of these areas.

Effects on Curricular Content

The potential effects of technology on curricular content are more evident in mathematics than science education. The major influence of technology on mathematics education appears to be its potential to shift the focus of instruction from manipulative to higher order skills: developing concepts, relationships, structures, and problem-solving (NCTM, undated). Much of the time currently devoted to proficiency with paper-and-pencil algorithms may be replaceable with new or previously neglected topics, constituting a different kind of mathematical preparation (Romberg, 1984).

What does this different kind of mathematical preparation consist of? In arithmetic, the use of the calculator makes estimation critical (The College Board, 1983, 1985a). Students must be able to estimate so that they can determine if the results of machine calculation are reasonable. If results appear incorrect, they must be skilled in mental arithmetic so that the location of particular errors can be detected.

As in arithmetic, the basic thrust of algebra has been to give students moderate technical facility (The Conference Board of the Mathematical Sciences, 1982). The calculator, however, eliminates the need to learn long, complicated algorithms, making such traditional topics as the calculation of logarithms and exponentials obsolete (NCTM, undated). Even the solution of quadratic equations and other algebraic expressions can be handled by widely-available microcomputer software (e.g., muMath), making technical facility far less important (The College Board, 1985a; Hosack, Lane, & Small, 1984). These computational aids allow more time to be devoted to the concepts underlying algebraic operations. Instead of focusing primarily on the manipulation of symbols, emphasis can be given to expressing and interpreting quantitative relations (Fey, 1984, cited in The College Board, 1985a).

The capabilities of the computer open new possibilities for the revision of geometry curricula. For example, the geometry of three-dimensional space is rarely included in current high school curricula. Yet students need well-developed spatial skills for the study of such subjects as engineering, architecture, graphic design, chemistry, biology, physics, geography, meteorology, astronomy, and medicine (The College Board, 1985a). The geometry of three-dimensional space can be made accessible to students through the powerful graphical capabilities of the computer (NCTM, undated).

In addition to the traditional areas of arithmetic, algebra, and geometry, the computer has made the introduction of new topics desirable. For example, at both the high school and college level, discrete mathematics (including logic, algebraic structures, and combinatorics), probability, and statistics are being viewed as primary candidates for inclusion or increased curricular emphasis (The College Board, 1985a; The Conference Board of the Mathematical Sciences, 1982; The Connecticut Mathematics Study Group, 1984; Mathematical Association of America, 1984; NCTM, undated). The move toward inclusion of discrete mathematics suggests a trend away from the teaching of calculus. This move may represent a substantial and fundamental shift in philosophy regarding high school and college mathematics education.

Besides new topics drawn from other branches of mathematics, the inclusion of a wide range of computer-related competencies is also being advocated. Among these competencies are such computer science topics as knowledge of programming and algorithms (The College Board, 1983; The Conference Board of the Mathematical Sciences, 1982; National Science Board, 1983). These skills are included because algorithmic thinking is central to mathematics and because many complex mathematics problems can be solved only through programming. In addition to these computer science skills, familiarity with graphics and other mathematical problem-solving software is recommended (National Science Board, 1983; Teague, 1984).

Effects on Curricular Delivery

In contrast to curricular content, calculator and microcomputer technology have the potential to substantially affect curricular delivery in both mathem... and science education. Among the effects on curricular delivery are using technology to demonstrate concepts, to teach content through experimentation, and to teach through programming.

Using calculators and computers to demonstrate concepts. Calculators and computers can be used to demonstrate concepts, thereby making abstract mathematical and scientific ideas easier to comprehend. As an example, the calculator (or computer) can be used to demonstrate the relationships among such trigonometric functions as sin(2x), 2sin(x) and 2sin(x)cos(x) (Kirst, 1980). These relationships can be discovered by constructing the graphs of each function, a task that can be accomplished efficiently by beginning trigonometry students only with an electronic aid. From the graphs they construct, students can easily see that sin(2x) does not equal 2sin(x) because their graphs are different, but that sin(2x) = 2sin(x)cos(x) is a reasonable hypothesis because their graphs are the same. While a formal proof of the latter relationship must still be completed, the calculator has helped provide a simple, but dramatic, demonstration to support the proof.

One of the main illustrative capabilities of the computer is its capacity for visual display. This capability particularly suits the computer to the demonstration of mathematical and scientific concepts (NCTM, undated; National Science Board, 1983). Visual display is, of course, nothing new to the classroom or lecture hall. The blackboard, and to a lesser extent, the overhead projector, are standard educational fixtures. The advantage of the computer, however, is that it presents a dynamic display, one that can show moving images and instantaneously change those images on command. For example, in mathematics, equations can be graphed and the effects of changes in parameters immediately presented. In science, different waveforms can be visually displayed and manipulated free of the influences of gravity and friction, permitting the illustration of wave properties that are difficult or impossible to show mechanically (e.g., Standing Waves). In both instances, instructors can demonstrate concepts for students in ways that are presumably more effective and interesting than those traditionally used (National Science Board, 1983).

Using calculators and computers to teach curricular content through experimentation. Besides enhancing the illustration of concepts, calculators and computers can be used to teach content through experimentation. For example, the Technical Education Research Center (TERC) has developed computer-based materials that allow students to conduct experiments using data gathered from the immediate environment ("Teachers Say Computers," 1985). Temperature and sound probes can be directly wired to the microcomputer to collect data, immediately graph it, and analyze results. Students are freed from the routine calculations and the mechanical task of graph construction that such an experiment would otherwise require, leaving more time to concentrate on discovering underlying concepts.

In addition to experimenting with scientific phenomena, experiments can be conducted in mathematics. For instance, as an introduction to logarithms, students can be asked to observe the function of the calculator log key and develop hypotheses about the properties and special cases associated with logarithms (Kirst, 1980). These hypotheses can be supported or refuted through further systematic trials. As a second example, the teacher may state that,

$$6^2 - 6 = 5^2 + 5$$

and ask whether this equality holds for all pairs of consecutive numbers. Students can test other consecutive pairs and finally generate a formal proof to show that:

$$n^2 - n = (n - 1)^2 + (n - 1)$$

With computers, mathematical experiments can be conducted using the <u>Geometric Supposer: Quadrilaterals</u>. This program allows the student to make any construction on, or take the measurements of, a quadrilateral. The construction or type of measurement is then recorded as an automatic routine which can be repeated on any other quadrilateral. Through this type of exploration, students can develop hypotheses about the properties of these figures and test those hypotheses on other figures from the same class (Schwartz & Yerushalmy, undated). For example, students can have the program sum the angles of each of several additional quadrilaterals. From the results, they might infer that a basic property of these figures is that the sum of their angles must always equal 360 degrees. Students can then test this hypothesis on quadrilaterals of different sizes and types (e.g., squares, rectangles, parallelograms) to determine if the hypothesis is correct.

A formal proof could then be demonstrated by the teacher or undertaken by the students.

While computers and calculators can help students conduct experiments with real data, computers also can help students discover important concepts and principles through experimental simulations. In science, software-based laboratory simulations designed to teach a wide variety of topics have been produced (e.g., see Conduit, 1985). These simulations allow high school and college students to perform experiments that would otherwise be too costly, complicated, time-consuming or dangerous to undertake ("Computer Aided Science Labs," 1985). For example, a genetics simulation called CATLAB allows students to mate domestic cats selected by coat color and pattern. The program then produces genetically-valid litters based on these matings, helping students discover the principles underlying transmission genetics. A second example, Tribbles, is intended to introduce students to the scientific method. Students see pictures taken by an orbiting space ship of a previously unexplored planet. The pictures show small, round creatures called tribbles whose location constantly changes. Students are responsible for systematically observing tribble patterns, constructing hypotheses about the rules that govern their behavior, and testing those hypotheses. A third example is the Computer Lab in Memory and Cognition which allows students to participate as subjects in significant experiments in this field. Using the program, students can collect data and compare their results individually and as a class to those reported in the scientific literature.

Finally, it should be noted that the software packages described can not ;e used to impart mathematical and scientific concepts. They also can be used to teach students the process of experimentation and how to use this process as a general learning and problem-solving tool.

Using calculators and computers to teach curricular content through programming. For mathematics in particular, it has been widely argued that programming can be used to teach important concepts and processes (The College Board, 1985a; The Conference Board of the Mathematical Sciences, 1982; Norris, 1981). As one example, the concepts and mechanics underlying the quadratic formula may be more deeply understood if taught through a few paper-and-pencil solutions followed by a programming exercise (The College Board, 1985a). Programming a calculator or computer to solve a quadratic equation requires a thorough understandir of the concepts and mechanics underlying the formula. One must know the equation well enough to state it in the incremental step-by-step terms required for electronic processing. One must also know it well enough to specify treatment for special cases, such as the handling of zero exponents and negative values. This thorough knowledge of the equation develops, argue advocates, as a result of programming it.

A second use of programming is to teach problem-solving skills. In mathematics, one of the most fundamental problem-solving skills is the development, use, and analysis of algorithms. Such skills are used in devising proofs in calculus and in applying algebraic formulae. Interestingly, algorithmic skills are also basic to programming: algorithms are developed and used to solve all manner of programming problem. The similarity between the problem-solving approaches found in the two disciplines suggests that programming can help foster the algorithmic thinking central to mathematical understanding (National Conference Board of the Mathematical Sciences, 1982).

In addition to algorithmic thinking, other problem-solving approaches are shared by mathematics and programming. In both disciplines, breaking a problem down into subproblems is a commonly-used strategy. The strategy is illustrated in mathematics by taking a complex algebraic expression and breaking it into several simple ones. In computer programming, the analogous action is to form a complex program by creating a series of simple "procedures," each of which performs some small aspect of the total program's function. Again, the similarity in problem-solving approaches has caused some to argue for the use of programming to teach mathematical strategies (The College Board, 1985a).

The Incorporation of Technology in the Classroom

Given the potential for curricular change embodied in computer and calculator technology, it is not surprising that some consider the widespread availability of these machines fundamental to learning in the mathematics and sciences. For instance, some professional associations have taken the position that every mathematics classroom should have as standard equipment a demonstration computer with a large-screen display (MCTM, 1984). Others have called the presence of computers and related electronic devices in each mathematics class as important as the availability of lab equipment for science instruction (The Conference Board of the Mathematical Sciences, 1982).

Despite these position statements, and notwithstanding the rapid influx of computers into secondary schools and colleges, there is good reason to believe that the use of calculators and computers in mathematics and science classrooms is limited. At the twelfth-grade level, calculators are reportedly used two or more periods per week in only a third of all classes (Crosswhite, Dossey, Swafford, McKnight, & Cooney, 1985). As for computers, research suggests that only 22% of secondary school mathematics teachers and 12% of science teachers use these machines instructionally (Becker, 1985). These individuals are, however, widely dispersed with at least one mathematics teacher found in over 50% of computer-owning high schools and one science teacher in over 30% of schools. At the college level, the use of computers in freshman year chemistry is reported to be essentially nonexistent (Lykos, 1982).

The limited use of new technology in classrooms may be attributable to several factors. Not the least of these are the cost of maintaining a mathematics or science computer lab, and the need to provide teachers with many hours of inservice training, to make modifications in the school's physical plant to insure adequate electrical power and security, and to obtain enough hardware and software to permit reasonable student access (Bennett, in press; Cline, Bennett, Kershaw, Schneiderman, Stecher, & Wilson, 1986). With respect to calculators, the barriers are more philosophical: opponents fear that students will not learn mental computation if calculators do it for them (Shumway, 1979). Still, the high level of agreement--across professional associations, state education departments, education commissions, and teachers--on the utility of technology for improving mathematics and science education is striking. Such agreement, in conjunction with the growing use of technology in society at large, argues for eventual incorporation of new technology into mathematics and science high school and college curricula.

Implications for Achievement Testing

On behalf of the College Board, ETS develops and administers achievement tests in the mathematics and sciences through two major programs: the Admissions Testing

Program (ATP) and the Advanced Placement (AP) program. The ATP achievement tests are used primarily in college admissions, and in guidance and placement after admission. Tests administered are intended to mirror the high school curriculum and include mathematics (two levels), biology, chemistry, and physics. Calculators (and presumably computers) are not permitted on any of the tests (The College Board, 1985b).

In contrast to the Admissions Testing Program, the primary purpose of the AP program is to provide a vehicle for high school students to develop and demonstrate mastery of college-level material so that credit, placement in advanced courses upon arriving in college, or both can be offered. This vehicle is provided by the publication of college-level course descriptions intended for use in the high schools, and by the administration of tests designed to measure achievement in areas covered by these courses. Exams administered through the program include the mathematical sciences (two in calculus and one in computer science), physics, chemistry, and biology. The use of calculators is permitted on the physics and chemistry tests, though memories must be cleared and peripheral devices capable of loading stored programs are excluded (The College Board, 1985c, 1985d). Calculators are not permitted on the mathematics tests because of concern for disparities in the availability of technology across socioeconomic groups, and for reasons of test security (e.g., to prevent the use of calculators programmed to solve particular types of problems) (The College Board, in press). Computers are not allowed on any of the exams.

As for all achievement tests, evidence of the validity of the ATP and AP measures in large part lies in the extent to which their content matches the curricula they are designed to represent. To the extent that the tests and the curricula they are intended to mirror diverge, test validity must be called into question.

To ensure a reasonable match between test content and curricula, both the AP and ATP programs invest responsibility for the development of test content specifications and items with committees composed of university and high school faculty. These development committees rotate membership periodically and meet at least annually (some meet several times a year) to review specifications, items, and tests. For the AP program, major content changes routinely are made on a biannual basis and reported in the current AP course description. For the ATP mathematics and science achievement tests, significant modifications are likely to be considered in response to the College Board's (1983) recent call for revision of the high school curriculum.

That the committee process works reasonably well is evidenced by the fact that many of the curricular changes called for have already been instituted into College Board tests. In the ATP mathematics test, for example, the computation required is typically straightforward and only incidental to the concepts tested. (The ATP tests in biology, chemi ,, and physics are similarly constructed to avoid cumbersome computation.) Computations using logarithms and interpolation, topics often cited for deletion from the curriculum, are not included. Probability, statistics, data interpretation, and recursive definitions--all deemed important by advocates of a new mathematics curriculum--are represented in examination specifications.

However, even with the committee mechanism, some problems in the overlap of the tests and curricula should be anticipated. An in-depth analysis of the match between the AP and ATP tests and the curricula they are designed to represent is beyond the scope of this paper. Still, some potential problem areas can be highlighted.

One such problem area relates to the testing of experimental processes and techniques. The AP and ATP science tests generally do not cover laboratory skills in any depth, in large part because of the difficulty involved in assessing these skills through conventional means (The College Board, 1985d). Perhaps as a result, colleges have reported that some AP candidates, while doing well on the examination, were at a serious disadvantage in their coursework because of inadequate lab experience (The College Board, 1985c).

As noted, computer-based laboratory simulations are becoming widely available. The development of these simulations may have several effects. First, there appears to be general agreement that the type of learning encouraged in experimental simulations is often superior to that achieved through traditional classroom activities. Such learning is more likely to actively engage the learner and to facilitate problem-solving behavior (Wallace, 1985). Because of the cost advantages of computers versus lab equipment, the use of simulations may become widespread ("Computer Aided Science Labs," 1985), with more high school and freshman college students spending more time on this activity. As a result, experimental techniques and skills may become a more important component of the high school and first-year college science curriculum. Ignoring the measurement of such skills may pose serious threats to the validity of the AP and ATP science tests.

A related effect of the development of simulations is that laboratory techniques and skills may become easier to assess. Traditional methods either could not successfully duplicate the context of the laboratory (as in paper-and-pencil techniques) or were too costly or otherwise difficult to implement (as in practical lab exercises). In contrast, the computer-based simulation can duplicate the experimental context with a reasonable degree of faithfulness, thereby facilitating assessment of the types of knowledge and skill needed to successfully perform in that milieu.

Additionally, many practical problems--such as copying the experimental procedures of one's neighbors--are eliminated (though, certainly, others are created).

A second potential problem area for conventional achievement testing relates to the possible inclusion in high school and first-year college mathematics curricula of more spatially-oriented topics, such as the geometry of three-dimensional space. The basic concepts underlying these topics will be demonstrated via computer and students will consolidate their understanding through exercises performed on the machines. Assessment of the mastery of these spatial concepts may be difficult, if not impossible, using paper-and-pencil media. Should spatial topics become an important part of these curricula, achievement testing programs will need to take steps to insure the proper representation of this content.

A third area of potential content mismatch is in computer skills. Knowledge of programming and algorithms is widely advocated as fundamental to, and even intertwined with, the study of mathematics (The College Board, 1983; National Science Board, 1983). At present, the ATP mathematics tests do not contain such content, while the AP Program includes a paper-and-pencil computer science examination among its offerings in the mathematical sciences. Paper-and-pencil items designed to assess some aspects of computing could be inserted into the ATP tests or, as in the AP Program, used to develop an additional offering. However, this approach to achieving greater content overlap with curricula is limited: the evaluation of computer competencies absent any interaction with the machine raises serious concerns about the type and level of computing skills measured ("Pascal-Based AP Test," 1985). These concerns have, in fact, prompted the College Board to appoint an ad hoc committee to study the addition of an interactive component to the AP Examination in Computer Science. The deliberations of this committee may be helpful in identifying more effective approaches to measuring computer skills on mathematics exams.

Fourth, a content mismatch may occur with respect to symbol manipulation. The ATP mathematics tests contain problems requiring the transformation of algebraic and trigonometric expressions, while the AP examinations require the computation of derivatives and the evaluation of integrals. As noted, microcomputer software (e.g., muMath) can now perform these functions for students. This capability raises two questions. First, if the use of such software becomes widespread, should manipulative skills continue to be tested at all? If not, such content can be removed from the tests through the development committee process and the problem of mismatch is solved. However, it is conceivable that the ability to use such software to perform manipulations will become important. If this should occur, a means for assessing these skills within the context of the AP and ATP tests may have to be found.

Finally, potential content issues are raised by the possible introduction of calculators for the ATP achievement tests. First, if calculators are to be permitted, mathematics problems similar to those used in a calculator-enhanced curriculum will need to be included. For example, instead of using items in which calculation is deliberately kept simple (e.g., through the use of numbers with only one or two significant digits), more numerically appropriate questions would need to be written. Such a change in content poses no serious difficulties. More problematic, however, is the fact that the introduction of calculators might make it <u>more</u> difficult to test skills deemed critical for proper calculator use: if these devices are permitted, estimation, mental arithmetic, and approximation skills cannot be easily assessed.

In conjunction with content overlap, a second type of validity evidence is the extent to which a test predicts important criteria. Such evidence is especially relevant to the validity of the ATP achievement tests because these measures are used in college admissions. The criteria these tests would be expected to predict consist of college grades. To the extent that test and college curricular content diverge, such predictive relations would be expected to attenuate, further weakening the case for test validity.

Aside from questions of test validity arising out of the potential mismatch between test content and curricula, the incorporation of technology in the curriculum poses credibility problems. One such problem is that the failure to use new technology in achievement testing makes the program seem out of step with the times--even if using that technology otherwise does not improve assessment. Testing programs may <u>appear</u> to be less valid if they remain tied to paper-and-pencil administration while the workplace, the school, and the home go "high tech."

A second potential credibility problem is associated with the synergistic relationship between test and curriculum. Clearly, achievement tests should be built to broadly reflect the essential subject-matter of a particular field. In this sense, curriculum drives test development. However, many school districts, in turn, key their curricula to particular tests so as to maintain or improve publicly reported performance levels. Here, testing drives curriculum (The Conference Board of the Mathematical Sciences, 1982; "Math Educators," 1985). The result of these two countervailing forces is a cycle that limits chances for substantive change.

The effects of this cycle are in some ways beneficial. Because change is so hard to effect, bandwagon movements and other passing fads are less likely to be reflected in any important way in either tests or curricula. If such transient effects were allowed to be reflected, chaos would result: curricula would differ widely from locale to locale and year to year, and tests and curricula would never be in agreement.

Recognizing that tests and curricula are interdependent, some educators have called for modifications in test content as a means of effecting large-scale curricular change (e.g., The Conference Board of the Matnematical Science, 1982). Such calls are likely to be resisted by testing programs on two grounds. First, as noted, evidence for the validity of achievement tests rests primarily on the match between curricular and test content. Any change in test content that increases its divergence with curriculum is a threat to test validity. Second, changes associated with new technology imply thorny operational problems. Instituting a computer-based lab simulation as part of an AP science test, for example, significantly reduces the number of students that can be tested concurrently, requires the presence of proctors familiar with computers, and raises questions of which brands of computer to use, among other things.

While these psychometric and practical problems may be legitimate, resisting change on either grounds likely will be viewed as an attempt to keep curricula from undergoing much-needed modification. On the other hand, leading curricular change by modifying tests may provoke charges that curricula are being dictated by the testing establishment. Clearly, testing programs will need to weigh carefully the advantages and disadvantages of either position before taking action.

Recommendations for Research

The implications for testing discussed above imply the need for various types of information. To gather this information, the following five research projects should be considered:

1. Survey high school and first-year college mathematics and science curricula. There can be no question that curricular change associated with the advent of new technology is being advocated by the major bodies that shape education: national commissions, professional associations, and state departments. What *is* open to question is the extent to which the suggested changes have filtered down to the classroom level. Are the changes evident in university course syllabi and district curricular statements? Further, are the changes actually reflected in the lessons and lectures of individual teachers and professors? Some attempts to collect information relevant to classroom practice have been made (e.g., Williams & Jones, 1978). However, far more information is needed. Without this information, it is impossible to know if achievement tests are actually out-of-step with curricula; while the tests may differ from the curricula of the state department, the national commission, and the professional association, they may match the ones commonly used in schools and colleges.

2. Analyze the content of AP and ATP mathematics and science tests in relation to major curricular trends. There is good reason to believe that the AP and ATP tests already

reflect many of the major curricular trends. Cumbersome computations, for example, are generally not required and problem-solving skills are generally emphasized. A precise description of how the tests diverge from major curricular trends, however, would be informative. Such description would need to be based on a careful analysis of major curricular trends at all levels-- from the classroom to the national commissions--and should focus particularly on identifying trends that bridge these levels. The results of this comparison should be fed back to the relevant College Board advisory and test development committees. These committees, in turn, should advise the Board on how instances of mismatch are to be handled.

3. Assess the practical implications of adding new content to existing tests versus developing new tests: As a result of the analysis conducted in #2 above, the advisory and development committees may identify topics--such as discrete mathematics or computer skills--that need to be better represented in the ATP or AP tests. Such topics can be represented by adding them to existing tests or by developing a new measure devoted solely to that content. Clearly, each strategy has different practical implications that will need to be identified and carefully assessed. Among the more obvious problems is whether to increase the length of the test or, alternatively, delete material to make room for new content. If material is to be deleted, what material should it be?

4. <u>Assess the implications of permitting the use of calculators on AP and ATP tests</u>: The use of calculators may have psychometric, administrative, and other implications for ATP and AP tests. In terms of psychometrics, studies have found the use of calculators to slow the rate of student response on some types of mathematics tests, implying a need for adjustments in test timing (Carpenter, Corbitt, Kepner, Lindquist, & Reys, 1981, in Lewis & Hoover, 1981; Lewis & Hoover, 1981). Other research has suggested that test scores can be affected negatively, particularly when students are uns[ure] when to use and not to use the device (The College Board, 1985e; Lewis & Hoover, 1981). Still other questions can be asked including the psychometric effects of different levels of familiarity with calculators among students, of using different types of calculators (e.g., programmable vs. not programmable), and of giving all students the same model or letting them use their own (Swinton, 1978).

With respect to administrative and other implications, the use of calculators is already permitted on the AP Physics and Chemistry tests. Certainly, these tests have developed a useful backlog of practical experience in addressing the problems posed by these devices. Knowing what problems have been encountered and how these were dealt with would be invaluable to the Board's committees in recommending the wider use of these aids. For example, have these programs found the use of calculators to be distributed as feared along social class or racial lines? Also, can the problems encountered be addressed in such a way as to permit the use of calculators on other AP and ATP tests, particularly ATP Chemistry and Physics?

5. Develop, administer, and psychometrically analyze a prototype computer-based science lab exam. The absence of content testing laboratory techniques and procedures would seem to be a substantial shortcoming of the AP and ATP science tests (The College Board, 1985c, 1985d). At the same time, laboratory simulation software is becoming more widely available and more highly regarded ("Computer-Aided Science Labs,' 1985; "Teachers Say Computers," 1985). Developing and pilot testing a laboratory simulation might provide testing programs with invaluable insight into the potential of such measures. The foundation for such a simulation already exists in a computer-based biology experiment developed for the College Board under the title, "Innovative Items" (ETS, 1980). A simulation such as this could be extended to cover a series of experiments and piloted as a laboratory component to one of the AP or ATP science tests.

Both practical and psychometric questions will need to be studied in relation to the administration of such as test. Among the practical concerns are whether enough computers can be found at a single location to service the typical number of examinees, what to do when machines break down, what brand(s) of computer to use, and whether knowledge of the computer will interfere with the measurement of achievement. Psychometric concerns include the extent to which the lab simulation measures reliably, measures something different from that assessed by the paper-and-pencil test, and--for the ATP tests particularly--adds to the predictive value of the examination.

Summary and Conclusions

Technology, particularly in the form of the microcomputer, is being incorporated rapidly into American education. Coincident with this rapid incorporation have been widespread calls for change in mathematics and science curricula. These calls have generally focused on the need to develop scientific literacy, a construct apparently composed of problem-solving and technological skills, among other things. The calls for curricular change appear motivated by the larger need to prepare students for college, employment, and citizenship, and to prepare our country for increased economic and military competition.

Calls for curricular change in the mathematics and sciences have been evident in two major areas: content and delivery. Changes in curricular content are more apparent in mathematics where the major influence of technology seems to be in its potential to shift the focus of instruction from manipulative to higher order skills, such as developing concepts, relationships, structures, and problem-solving. With respect to curricular delivery, trends in science and mathematics are evident in three areas. These are using calculators and computers to (1) demonstrate concepts, (2) teach curricular content through experimentation, and (3) teach content through programming.

While agreement on the educational benefits of technology appears to be shared by national commissions, state departments of education, professional associations and teachers alike, the use of calculators and computers in mathematics and science courses is limited. For computers, barriers to full implementation include cost and other practical problems, while for calculators the major barriers appear philosophical. Still the broad base of support for implementation suggests eventual widespread use in mathematics and science courses.

This eventual widespread use has important implications for College Board mathematics and science achievement tests. Threats to the validity of these tests primarily stem from a potential mismatch between test and curricular content. Such a mismatch might be expected to occur in several areas. First, laboratory science skills are generally not assessed by these testing programs; yet, the availability of computer simulations may cause these skills to play a greater role in the curriculum and make them easier to assess. Second, the advent of computers makes the inclusion of more spatially-oriented mathematics content possible; however, these skills may not be assessed easily by paper-and-pencil media. Third, computer skills are becoming a more frequent part of the mathematics curriculum, but as yet, the testing programs have only been able to offer paper-and-pencil measures of these skills. Fourth, the ability to manipulate symbols is expected to become less critical as the use of software to accomplish this task increases, thereby shifting curricular emphasis to computer use, a skill testing programs currently are not equipped to assess. Finally, the introduction of calculators poses a dilemma: skills made important by these devices--mental arithmetic, estimation, approximation--will be difficult to assess if the use of these devices is permitted on tests.

In addition to test validity, the widespread use of technology has implications for program credibility. Testing programs that do not incorporate technology may be perceived as less valid because of this omission. Second, because achievement tests are often perceived as driving curricula, delaying changes in test content until they appear in curricula may be viewed as attempts to impede needed educational change. Modifying test content <u>before</u> curricula change likewise may be negatively perceived, this time as driving curricula.

Clearly, the growing use of technology in high schools and colleges poses complex problems for testing programs that will need to be carefully weighed. To make informed decisions about these problems, research might be undertaken to determine: (1) the extent to which calls for curricular change are actually being reflected at the classroom level; (2) the extent to which AP and ATP achievement tests diverge from major curricular trends; (3) the practical implications of adding new content to existing tests versus adding new tests; and (4) the practical implications of permitting the use of calculators. Finally, to develop first-hand experience with computer-based achievement testing, a prototype science lab exam might be created, pilot tested, and psychometrically analyzed.

References

Barbour, A. (1984, October). EL's fourth annual survey of the states: Computing in America's classrooms 1984. Electronic Learning, 39-44.

Becker, H. (1985, May). Instructional uses of school computers: 1983 and 1985 national surveys. Seminar presented to the staff of Educational Testing Service, Princeton, NJ, May 1985.

Benderson, A. (1985). Beyond computer literacy. Focus, 16.

Bennett, R. E. (In press). Identifying a purpose for computer education programs. In R. E. Bennett (Ed), Planning and evaluating computer education programs. Columbus OH: Charles Merrill.

California State Department of Education. (1985). Model curriculum standards (Grades nine through twelve): Mathematics. Sacramento, CA: Author.

Carpenter, T. P., Corbitt, M. K., Kepner, H. S., Lindquist, M. M., & Reys, R. E. (1981). Results and implications of the Second National Assessment of Mathematics. Reston, VA: National Council of Teachers of Mathematics.

Cline, H. F., Bennett, R. E., Kershaw, R. C., Schneiderman, M. B., Stecher, B., & Wilson, S. (1986). The electronic schoolhouse: The IBM Secondary School Computer Education Program. Hillsdale, NJ: Lawrence Erlbaum Associates.

The College Board. (1983). Academic preparation for college: What students need to know and be able to do. New York: Author.

The College Board. (1985a). Academic preparation in mathematics: Teaching for transition from high school to college. New York: Author

The College Board. (1985b). Taking the Achievement Tests: The official guide to the College Board Achievement Tests. New York: Author

The College Board. (1985c). Advanced Placement course description: Chemistry (May 1986). New York: Author.

The College Board. (1985d). Advanced Placement course description: Physics (May 1986). New York: Author.

The College Board. (1985e). Advanced Placement course description: Mathematics (May 1986). New York: Author.

The College Board. (In press). Advanced Placement course description: Mathematics (May 1987, May 1988). New York: Author.

Computer-Aided Science Labs Said to Boost Science Education. (1985, June 5). Education Computer News, p. 6.

Conduit. (1985). Catalog of educational software. Iowa City: The University of Iowa.

The Conference Board of the Mathematical Sciences. (1982, December). The mathematical sciences curriculum K-12: What is still fundamental and what is not (Report to NSB Commission on Precollege Education in Mathematics, Science, and Technology). Unpublished manuscript.

The Connecticut Mathematics Study Group. (1984). A guide to curriculum development in algebra I, geometry, and algebra II. Hartford, CN: State of Connecticut, Department of Education.

Crosswhite, F. J., Dossey, J. A., Swafford, J. O., McKnight, C. C., & Cooney, T. J. (1985). Second international mathematics study summary report for the United States. Champaign, IL: Stipes Publishing Company.

Educational Testing Service (ETS). (1980, October). Beyond paper and pencil. Princeton, NJ: Author.

Educational Testing Service (ETS). (1985, Summer). The computer intensive environment: Study explores phenomenon, options. ETS Developments, 31, 10-11.

Florida Department of Education. (Undated). Student performance standards of excellence for Florida schools in mathematics, science, social studies and writing. Tallahassee, FL: Author.

Fey, J. T. (Ed). (1984). Computing and mathematics: The impact on secondary school curricula. Reston, VA: National Council of Teachers of Mathematics.

Four million students will own microcomputers by 1987, study says. (1984, May 23). Chronicle of Higher Education, p. 13.

Georgia Department of Education. (1981). Mathematics for Georgia secondary schools. Atlanta, GA: Author.

Hosack, J., Lane, K., & Small, D. (1984). Report on the use of a symbolic mathematics system in undergraduate instruction. In Mathematical Association of America (Ed), Preliminary report on discrete mathematics in the first two years. Author.

Kirst, B. (1980, September). Uses of calculators in secondary mathematics. Calculator Information Center Information Bulletin No. 8.

Kulik, J. A., Bangert, R. L., & Williams, G. W. (1983). ffects of computer-based teaching on secondary school students. Journal of Educational Psychology, 75, 19-26.

Kulik, J. A., Kulik, C. C., & Cohen, P. A. (1980). Effectiveness of computer-based college teaching: A meta-analysis of findings. Review of Educational Research, 50, 525-544.

Lewis, J., & Hoover, H. D. (1981, April). The effect on pupil performance of using hand-held calculators on standardized mathematics achievement tests. Paper presented at the annual meeting of the National Council on Measurement in Education, Los Angeles.

Lykos, P. (1982, September). CPT questionnaire on computers in undergraduate chemistry (Memorandum). Washington, D.C.: American Chemical Society, Committee on Professional Training.

Math Educators Said Unprepared for Reform Agenda. (1985, May 1). Education Week. p. 9.

Mathematical Association of America. (1984). Preliminary report on discrete mathematics in the first two years. Author.

Montana Council of Teachers of Mathematics (MCTM). (1984, Fall). MCTM Position Paper on Integrating Technology into the Mathematics Curriculum.

Murphy, R. T., & Appel, L. R. (1984). Evaluation of the Writing to Read instructional system. Princeton, NJ: Educational Testing Service.

National Commission on Excellence in Education. (1983, April). A nation at risk: The imperative for educational reform. Washington, D.C.: U.S. Department of Education.

National Council of Teachers of Mathematics (NCTM). (1980a). An agenda for action: Recommendations for school mathematics of the 1980s. Reston, VA: Author.

National Council of Teachers of Mathematics (NCTM). (1980b, October). A position statement on computers in the classroom. Reston, VA: Author.

National Council of Teachers of Mathematics (NCTM). (Undated). The impact of computing technology on school mathematics (Report of an NCTM conference). Reston, VA: Author.

The National Science Board Commission on Precollege Education in Mathematics, Science, and Technology. (1983). Educating Americans for the 21st century. Washington, D.C.: National Science Board.

Norris, D. O. (1981, January). Let's put computers into the mathematics curriculum. Mathematics Teacher, 24-26.

Pascal-Based AP Test Hits Rough Road. (1985, March). Classroom Computer Learning, p. 13.

Quality Education Data, Inc. (1985, Spring). Microcomputer usage in schools: 1984-1985. Denver, CO.

Ragosta, M. (1983). Computer-assisted instruction and compensatory education: A longitudinal analysis. Machine-Mediated Learning, 1, 97-126.

Riccobono, J. A. (1985). School utilization study: Availability, use, and support of instructional media. Washington, D.C.: Corporation for Public Broadcasting.

Romberg, T. A. (1984). School mathematics: Options for the 1990s (Volume 1: Chairman's report of a conference). Washington, D.C.: U.S. Department of Education.

Schwartz, J. L., & Yerushalmy, M. (undated). The geometric supposer: Quadrilaterals. Pleasantville, NY: Sunb rst Communications.

Shumway, R. J. (1979). Hand calculators: Where do you stand? In B. C. Burt (Ed), Calculators. Reston, VA: National Council of Teachers of Mathematics.

Swinton, S. (1978). Variables to consider in hand-held calculator studies (Internal memorandum). Princeton, NJ: Educational Testing Service.

Teachers Say Computers Could Revive Dying School Science Labs. (1985, June 5). Education Computer News, p. 6.

Teague, W. (1984). Alabama course of study: Mathematics K-12 (Bulletin 1984, No. 16). Montgomery, AL: Alabama State Department of Education.

THE Journal. (1984). Microcomputers in education: 1985 market research report. Irvine, CA: author.

THE Report. (1985, April). Education: A big ticket market. THE Report, p. 2.

Tucker, M. S. (1985, January). Computers in the schools: Has the "revolution" passed or is it yet to come? Paper presented at the annual meeting of the Association of American Publishers, New York City.

Twentieth Century Fund Task Force on Federal Elementary and Secondary Education Policy, 1983. Making the grade. New York: Twentieth Century Fund.

Wallace, M. L. (1985). Computer simulations: A means for integrating realistic problem solving into the curriculum. In National Council of Teachers of Mathematics (Ed), The secondary school mathematics curriculum (1985 Yearbook). Reston, VA: National Council of Teachers of Mathematics.

Williams, S. I., & Jones, C. O. (1978). A survey of the use of hand-held calculators in Advanced Placement Calculus courses (P78-1). Princeton, NJ: Educational Testing Service.