Computer Related Curricular Changes in Traditional Mathematics

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The author has been long concerned with the proper role for the computer in undergraduate instruction in mathematics. This was, in part, prompted by the dramatic shift he observed in engineering education which took place in the early 1960s as students gave up slide rules and embraced computers as their principle tool. Much credit for this rapid transition should go to the Ford Foundation (Michigan U.) project on Computers in Engineering Education [1] which developed computer-oriented materials for traditional courses and trained many visiting faculty in the use of computers and the related instructional materials generated. Although trends in the employment opportunities for undergraduate students in mathematics showed the need for substantial curricular changes also, repeated efforts to get a counterpart of the Michigan Engineering Education effort funded for mathematics were futile.

In 1964 the Committee on the Undergraduate Program in Mathematics published "A Course of Study for Mathematics Majors Expecting to Work in Computing [2]." This included 30 semester hours of traditional mathematics (12 hours in beginning analysis, 6 hours in advanced calculus, and 3 hours each in linear algebra, algebraic structures, numerical analysis, and probability and statistics). In addition to an introductory course in computer science, this mathematics core was to be augmented by 6 elective hours of advanced topics in, or closely related to, computer science. We needed to add only one course at F.S.U. to give our majors a chance to comply formally with those CUPM standards. Many students of that era moved successfully into industry or graduate school from that program.

However, most of our mathematics core courses were taught by faculty with little, if any, exposure to computing. Hence, the CUPM suggestion in the above report that, for traditional courses, "Theory and simple techniques of numerical computation should be introduced where relevant," usually had little effect.

To help focus attention on broad computer-related curricular changes needed in mathematics, the author organized, in 1966, a national symposium at Florida State University sponsored by the Association for Computing Machinery. Approximately fifty invited department heads or designated deputies participated along with an equal number of additional faculty. William Atchison, Wallace Givens, Nathaniel Macon, Francis J. Murray, and the author gave papers suggesting computer-oriented curricular changes in mathematics which were included in a Symposium Report [3] published in the _Communications of the ACM_. The report also contained implementation suggestions made by a second panel consisting of William Duren, John Hamblen, Russell Poor, and Leland Shaner. The last speaker of today's panel, Anthony Ralston, also had, in one sense, the last word of the 1966 symposium. In his _Computing Reviews_ [4] analysis of our remarks he said:

> The only remarkable thing about the impact, thus far, of computing on undergraduate mathematics instruction, is its absence. This thesis is amply borne out by the papers in this symposium by eminent mathematicians and computer scientists. For example, Murray suggests that elementary programming should be taught as part of or in parallel with first year calculus. He correctly points out that

> the computer can be used to investigate concepts and develop understanding. How strange and sad it is that this idea still has an air of novelty about it! Indeed the trend in undergraduate mathematics instruction would seem to be aimed at ignoring the computer, if at all possible. Instead of enhancing the value of first year calculus by properly integrating numerical techniques into presentations of differentiation and integration, writers of new textbooks seem intent on hiding connection between these numerical techniques and the basic definitions of the derivative and integral. In this, they reflect the dominant opinion in most mathematics departments. It is barely believable that the desirable trend toward introducing students to linear algebra at an early stage has not been accompanied by an increase in the numerical linear algebra contents of such courses, which could be the source of many useful insights.

Shortly after this symposium, Florida State University became the host institution for a consortium of seventeen major universities, The Center for Research In College Instruction in Science and Mathematics (CRICISAM). The author persuaded the CRICISAM Board to undertake the curricular modifications suggested by the ACM panelists and the 1964 CUPM report and helped write a proposal to raise NSF funds therefor. This led to the CRICISAM Computer Oriented Calculus text [5] which went through three editions and was used for one or more sequences of calculus on about one hundred campuses. Dr. Gail Young served as Chairman of the National Advisory Committee which supervised the planning and production of this prototype text, and Warren Stenberg and Robert J. Walker were the principle authors. Stenberg and the author were co-directors of NSF College Faculty Institutes in 1969 and 1970 where computer-naive faculty came to learn computer programming and familiarize themselves with the CRICISAM approach to calculus. Pledged to try their hands at teaching computer-oriented calculus, the Institute participants then returned to their home campuses. A more detailed account of the CRICISAM calculus project and its impact on undergraduate mathematics can be found in the author's paper [6].

Other forces soon began to influence computer related changes in mathematics instruction. In 1967 the National Science Foundation sponsored a Conference on Computers in Undergraduate Education: Mathematics, Physics, Statistics, and Chemistry [7]. Conclusions of the Mathematics Panel Meeting at the Science Teaching Center, University of Maryland, included the following underlined recommendations:

> . . . it is the opinion of the Mathematics Panel that computing activities and relevant areas of numerical analysis should be integrated into the first college mathematics course and in subsequent courses when appropriate and natural. . . Wider experimentation in designing and introducing new courses in applied mathematics, in which computers play a central role, either in classroom instruction, or in individual work on the part of the student, is needed. In such courses, bold new emphasis should be put on model building and algorithmic solutions of a variety of problems.

Special topics in combinatorial theory and operations research were cited as illustrations of possible significant use of the computer in the classroom. A discussion of display devices, which make it possible to integrate theoretical and computational aspects of mathematics in a way impossible without the computer, ended with the recommendation that, ". . . experimentation with the development of computer connected display devices and appropriate software for classroom instruction in mathematics be undertaken."

It seems significant that these were the findings of a conference to which computer scientists were not invited, so that the suggestions were coming from mathematicians without a personal bias toward computing; the same may be said for a majority of the panel members of CUPM that have recognized the importance of computer-related changes in the basic offerings in mathematics. In preparing a 1975 grant proposal for computer-related curricular activity in mathematics, the author quoted eleven relevant reports made by CUPM panels, including the one previously cited from 1964. Key ideas from several of the more recent CUPM panels seem worthy of citing at this time.

We quote from the May, 1971 "Recommendations for the Undergraduate Program in Computational Mathematics" [8]:

> Finally, the computer has begun to have a direct effect upon mathematics courses themselves. New courses, particularly in computationally-oriented applied mathematics, are being introduced into many mathematical curricula, and traditional courses are being modified and taught with a computer orientation. An an example of the latter we cite only the teaching of calculus using the text, Calculus, A Computer Oriented Presentation, published by the Center for Research in College Instruction in Science and Mathematics.

This report went on to say:

> . . . trends indicate a need for the mathematics community to accept a responsibility for mathematical or scientific computing, and to broaden educational opportunities toward a more encompassing "Mathematical Science" in which students may explore the areas of overlap between pure and computational mathematics, as well as computer science. There is thus a need for innovative undergraduate programs which provide for a wide range of options, different opportunities for graduate study, and a variety of future careers . . In designing its program the Panel has taken the following path . . . Several new computer-oriented mathematics courses are described here; at the same time, some standard computer science and mathematics courses are included and, in particular, no recommendations are made concerning the redesigning of standard mathematics courses, such as the calculus, to include computer use. Where they are available, such computationally-oriented basic mathematics courses could be ideal components of this program, but their definition still requires considerable study and experimentation.

An outgrowth of the above recommendation may be found in the paper by Alan Tucker in this symposium. This report recommended twelve courses in the basic component for an undergraduate program in computational mathematics. Five courses were picked from the 1965 CUPM report "A General Curriculum in Mathematics for Colleges." These included introductory calculus, two courses in mathematical analysis, elementary linear algebra, and advanced muilt-variable calculus. Other courses were computational models in problem solving, introduction to numerical computation, combinatorial computing, differential equations and numerical methods, introduction to computing, computer organization and programming, programming languages, and data structures. Elective components to round out the major could come from mathematics, probability and statistics, computationally-oriented mathematics, other applied mathematics, computer science, or other relevant disciplines with particular suggestions cited for each of the above categories. It should be noted that the report cited did not address itself to the training of computer scientists, but to the education of applied mathematicians who will know how to use and apply computers. It was designed to meet the needs of students who planned graduate study in computationally-oriented applied mathematics. The panel noted that several of the courses recommended will meet the requirements of mathematics students and might be appropriate for secondary mathematics school teachers.

Another CUPM panel made recommendations in 1971 for "A Course in Basic Mathematics for Colleges [9]." This panel proposed a single, flexible, one-year course, Mathematics E, which would replace a combination of existing courses under such titles as college arithmetic, elementary algebra, intermediate algebra, and introduction to college mathematics. This course would frequently be the terminal course in mathematics and represent a minimal general education requirement. According to the report:

> The main aim of this course will be to provide the students with enough mathematical literacy for adequate participation in the daily life of our present society. One device for meeting this need is the introduction of flow charting and of algorithmic and computer-related ideas at the beginning of the course. These ideas permeate the course, encouraging the student to be precise in dealing with both arithmetic and non-arithmetic operations. However, the presentation of computer-related ideas in the course will not depend on the availability of actual machines. Topics of everyday concern, such as how bills are prepared by a computer, calculation of interest in installment buying, quick estimation, analysis of statistics appearing in the press, and various job-related algebraic and geometric problems, are mainstays of the syllabus.

The proposed course outline starts with a section on flow charts and elementary operations and indludes sections on computer concepts, rational numbers, linear polynomials and equations, geometry, statistics, and probability. Furthermore, the outcome consists of a general discussion of the computer, a treatment of computer uses in modern society, an elementary instruction in programming, and applications to other material already presented in the course. In its commentary on the outline, this report states:

> The purpose of introducing and utilizing computer-related ideas is basically the psychological one of getting the students involved with and thinking about mathematics. In a course of the kind we describe this point is likely to be of crucial importance. The Panel has more than adequate anecdotal evidence that the injection of computing will provide very strong motivation for the student. A secondary reason is the ubiquity of the computer in our present society and the need for the students to understand its potentialities and limitations in order to function as citizens and employees.

In January 1972 CUPM issued a commentary on "A General Curriculum in Mathematics for Colleges[10]." In discussing mathematics 1 and 2, the first courses of the calculus sequence, the Panel said:

> The computational aspects of calculus should be the center of attention in mathematics 1 and 2. This means both the techniques of differentiation and integration and the numerical-computational methods that go along with them. Many people believe that a computer should be used, if possible, to supplement the formal procedures and reinforce their teaching. However, CUPM is not prepared at the present time to provide any specific guidelines for how the computer should be used in calculus courses or how the traditional material of calculus ought to be modified in the light of the availability of computers.

The CUPM report of October 1972 on "Recommendations on Undergraduate Mathematics Courses Involving Computers" [11] speaks even more directly to our topic. After citing "The Four Ways in which the Computer can Influence Undergraduate Mathematics Education" as:

(i) Computing can be introduced into trational mathematics courses;

(ii) New courses in computationally-oriented mathematical topics can be designed;

(iii) The entire curriculum can be modified to integrate computing more fully into the student's program;

(iv) Computers and computer-related devices can be used as direct aids to mathematical instruction.

The report went on to say:

> . . . Nearly every student taking mathematics courses can benefit from some computer-oriented mathematics instruction. The use of computers is beginning to pervade all phases of life in our society, and students need to become familiar with some aspects of computing. Many mathematics departments have observed that well over half of their undergraduate majors enter computer related careers or graduate programs after graduation. Clearly, these students would benefit considerably from computer-oriented courses and curricula.

The author feels that ways (ii) and (iii) cited by CUPM are much more costly and less likely to be effective methods of introducing badly needed computer-related topics into mathematics instruction than are ways (i) and (iv) which form the thrust of his present work under NSF CAUSE and LOCI grants.

This report proposed computer applications in elementary functions, the calculus sequence, discrete mathematics, linear algebra, ordinary differential equations, probability, mathematical-computer modelling, and advanced algebra courses. In its concluding section on changes in instructional techniques, the importance of bringing computational results into the classroom was stressed. Transparancies, with an over-head projector to blow up computational results or computer generated graphs, was one possible means of doing this, while videotaped or film presentations with computer-produced graphics was another. A third possibility was that of an on-line terminal with a cathode-ray tube display device via television monitors so that a large class could participate in the interactive computation in progress.

As one might expect, the January, 1972 CUPM report on "Applied Mathematics in the Undergraduate Curriculum" [12] contained a section on the use of computers in applied mathematics and stated that, "Mathematics education has been influenced in several ways by the recent trend toward the widespread use of computers." The report drew attention to various ways in which machine experience can reinforce ideas and techniques which the student is learning and thereby contribute to the teaching of applications. It was pointed out that the use of computers made it possible to consider situations with a much greater complexity than would be possible if the numerical work were done by hand or desk calculator. This concept was illustrated by a ten-point discussion of a project involving the study on a rocket trip to the moon. Many of the standard courses outlined would naturally involve student use of computers.

Over the years, other CUPM studies have recommended computer-related mathematics courses for undergraduate students in special categories. One of the earliest of these was "Tentative Recommendations for the Undergraduate Mathematics Program of Students in the Biological Management and Social Sciences," January, 1964 [13]. The use of flowcharts to clarify computational activities for business students was recommended that early. In the discussion of the calculus series for those students, the concept of a function, comparable to a computer subroutine with input and output, was stressed. The linear algebra course was to contain approximately thirteen class periods devoted to computation, with the constructive approach to manipulating linear equations being stressed. The proposed level of study in probability and statistics would naturally lead to computer applications in statistical computations. In 1969 CUPM turned its attention to "A Transfer Curriculum in Mathematics for Two Year Colleges [14]." The section on the computer in two year colleges recognized the importance to university-bound junior college students of the availability of not only computer science and computer programming language subjects, but also of a course which emphasizes the integration of the computer into the traditional first two years of college mathematics. It was pointed out in this report, now nine years old, "That computers are rapidly being introduced into secondary schools both physically and as a part of the curriculum." This report also stated that, "The two year college student should be prepared to introduce computing into mathematics courses wherever relevant and appropriate," and "All of our recommended courses can make good use of flowcharts, algorithms, and computer program assignments."

The last CUPM report to be cited is "Recommendations on Course Content for the Training of Teachers of Mathematics," August, 1971 [15]. In the prelude to its recommendations, the following appeared:

> Computers have already had a phenominal impact on the high school mathematics curriculum in supplementing and, in part, replacing traditional formal methods by algorithmic methods. As access to digital computers becomes more common, one can expect both the flavor and content of high school mathematics courses to change dramatically. In schools where such facilities are already available, it has become clear that opportunities for experimentation and creative outlet, using the computer as a laboratory device, are within the reach of many students whose mathematical ability, motivation, or background would preclude any comparable experience in a formal mathematical setting. Moreover, it has been found that certain abstract mathematical ideas are understood and appreciated more completely when experience is first obtained through the use of a computer. Algorithmic and numerical techniques should therefore be given strong consideration in all courses in which they are appropriate; and, wherever computing facilities are available, use of the computer should be a routine part of these courses.

In its discussion of the calculus sequence, the report said: "It is also desirable to take advantage of the growing role of computers in introducing mathematical concepts." Prospective teachers, in a separate recommendation, were urged to obtain experience with applications of computing, including use of one higher level programming language.

Three of our previously cited recommendations were applicable to the training of pre-college teachers of mathematics. Considerable activity in computer-related mathematics instruction at the pre-college level has been underway for a long time. Important work was done in this area by the School of Mathematics Study Group which produced, in the mid 1960s, a course entitled "Algorithms, Computation, and Mathematics" [16] which shared its acronym, ACM, with the Association for Computing Machinery type-personnel who served on its writing team. Dr. Warren Stenberg, who was one member of that team, later became the principle author for the computer-oriented aspects of the CRICISAM calculus text, borrowing many ideas from that pioneer SMSG effort. Computer use for instruction from the elementary grades through high school has continued to grow. The ACM Education Board now has a special subgroup concerned with this aspect of computer-related instruction. The recent dynamic explosion of the market for the microcomputer and the inexpensive home-computer type variation thereof can only help accelerate the spread of computer use at the pre-college level. The community of computer knowledgeable professionals in mathematics should give attention and provide guidance to those introducing computer topics in mathematics at these lower levels.

Another aspect of computational revisions affecting pre-college mathematics is the tremendous growth in the availability and use of hand-held calculators whose price has dropped to 10% of that four years ago. According to the "State of the Art Review on Calculators" [17] from the Calculator Information Center in Columbus, Ohio, surveys conducted in a Kansas public school system of 22,000 students showed that owners of calculators at elementary, junior high, and senior high levels in 1977 were approximately 23%, 35%, and 42% respectively of the student bodies; whereas, students having access to calculators due to sharing in the classroom ranged from 62% to 80% in all three categories. This article summarized a report by its author, Marilyn Suydam, of a survey of the arguments given in defense of or against using the calculators in the classroom.

The May 1978 issue of The Mathematics Teacher [18] is devoted almost entirely to the use of calculators and/or computers in secondary school mathematics. It contains sixteen articles or special feature sections concerned with these two topics. Included in this issue were position statements on both the use of minicalculators and on the use of computers in the classroom. Excerpts from these position statements follow:

> With the decrease in the cost of the minicalculator, its accessibility to students at all levels is increasing rapidly. Mathematics teachers should recognize its potential contribution as a valuable instructional aid. In the classroom, the minicalculator should be used in imaginative ways to reinforce learning and to motivate learners as they become proficient in mathematics.
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> The Board of Directors has adopted the following goal for the Council: 'To encourage the development and evaluation of curriculum and instructional materials incorporating the use of the hand-held calculator and other computational devices.' A regularly updated bibliography, 'Minicalculator Information Resources,' is available free on request from the NCTM Headquarters.
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> . . . Although computer have become an essential tool of our society, their diverse and sustained effects on all of us are frequently overlooked. The astounding computational power of the computer has altered priorities in the mathematics curriculum with respect to both content and instructional practices. Improvements in computer technology continue to make computers, minicomputers, and programmable calculators increasingly accessible to greater numbers of students at reasonable cost.
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> An essential outcome of contemporary education is computer literacy. Every student should have firsthand experience with both the capabilities and the limitations of computers through contemporary applications. Although the study of computers is intrinsically valuable, educators should also develop an awareness of the advantages of computers both in interdisciplinary problem solving and as an instructional aid. Educational decision makers, including classroom teachers, should seek to make computers readily available as an integral part of the educational program.

We have looked rather extensively at justifications for computer-related curricular activity. Let us now examine some of the progress which has been made. One center of activity were the modules in computer-extended mathematics, produced in the computing and mathematics curriculum project at the University of Denver under the joint direction of Dr. William S. Dorn and Dr. Ruth I. Hoffman. One of the numerous modules produced by that project, active in the early 1970s, is cited as reference [19].

A major center for computer-related instruction across the board has been Dartmouth College, under the leadership of its Computer-Oriented Mathematician/President John Kemeny. One Dartmouth activity involved project COMPUTe, funded by the National Science Foundation for the period 1972-74. Leaders in this project were Tom Kurtz, Arthur Luehrmann, and A. Kent Morton. The purpose of this project was to collect materials, which had already successfully faced the acid test of classroom use, from university faculty and then produce and publish high quality course materials from those raw materials. Many of the topics covered were from mathematics or from application areas frequently treated in mathematics courses. A treatment of the objectives, rationale, and procedures for project COMPUTe appears in [20].

Dartmouth has served as a model for maximal computer involvement in instruction. The unusually high level of computer literacy on the part of Dartmouth students and faculty was documented in [21]. For instance, 93% of the Dartmouth student class of 1975 had used the computer with more than 70% having written one or more assigned programs in regular classes. Higher percentages, at the time of the report, had already been attained by the classes of 1976 and 1977. Furthermore, over 45% of the faculty had also written a computer program.

A joint study of the American Mathematical Society and the Mathematical Association of America was published in 1975 entitled "Calculus and Computing [22]." This resulted from a joint committee on the Influence of Computing on Mathematical Research and Education and a conference which it organized on this topic in Washington, D.C. in January, 1975. Therein, case studies are presented of computer-related calculus projects at Dartmouth, Duke, Georgia Tech., Gettysburg College, Mohawk Valley Community College, Purdue University, and the Universities of Illinois, Maryland, and New Mexico. In addition, some general observations about the problems involved, some sample computer problems, a discussion of practical aspects of computer use in calculus, and a bibliography were included.

Another center for modular development in mathematics, which has been computer-related in part, is the Education Development Center in Newton, Massachussetts. An earlier project, CALC, produced modular monographs in calculus to supplement existing texts. Typical of the project CALC output was a 132 page booklet on "Integration for a Course in Computer and Laboratory Calculus [23]." A current EDC project, UMAP, has been designed to overcome the lack of suitable materials on applications of mathematics needed to meet the requirements of the growing diversity of students in mathematics and their general lack of motivation. Monographs are to be in ten to twenty page units with specifically stated prerequisites and objectives. They can be selected individually to supplement lectures from standard texts or combined in assortments to provide text material for complete courses. Ross Finney has recently been named to head the UMAP project.

Another source of curricular material has been CM Publications at Illinois Institute of Technology, where computer-enriched modules have been developed with the support of the National Science Foundation and the EXXON Education Foundation. A typical module from that project is cited [24].

Since 1970 the Annual Conferences on Computers in the Undergraduate Curricula have served as a focal point for sharing information about computer-related mathematics curricular activity. The Ninth such Conference, held at the University of Denver in June, 1978, was no exception. Two sessions of papers on mathematics, one on statistics, and two on computer science were directly relevant to instruction in the mathematical sciences; whereas, many other sessions contained papers on techniques and applications related to mathematics instruction. On the last page of the Proceedings of this Ninth Conference [25] is an order form for obtaining copies of all previous Proceedings from Ted Sjoerdsma, at the University of Iowa, at $10 each.

Many individual papers, relevant to our topic, have appeared at sessions of the Mathematical Association of America, at the ACM Special Interest Group for Computer Uses in Education, or in the publications of those and similar organizations. We close our citation of sources by reference to CONDUIT--a National Science Foundation-funded multiuniversity project led by James W. Johnson at the University of Iowa. CONDUIT members or subscribers have access to reviewed and tested curcirulum packages which have been thoroughly documented for ease in portability between campuses. See, for instance, the guidelines for such documentations cited in [26].

In a recent paper [27], the author summarized some of the reasons why the total impact of such highly recommended computer-related curricular revisions has fallen far behind desirable goals. For instance, the computer-related calculus sequence, in a typical institution of higher learning, would be fought by computer-naive faculty lacking the background or motivation to accept department-wide efforts to modify the sequence. Where it is suggested that courses be modified to involve a programming prerequisite on the part of the students, there is reluctance to make such a requirement for a course on the part of instructors who lack the programming skill themselves. The approach which the author has taken in his current NSF CAUSE and LOCI grants has been to develop modules in which the computer output, produced with annotation and documentation, is related to the normal assignments in a traditional course in such a way that it can be helpful in understanding the topic better without requiring computer programming skills on the part of either the instructors or the students using it. It is hoped that this intermediate stage of painlessly introducing computer-related material will help larger percentages of faculty to see the advantages of a fuller implementation of computer use in undergraduate mathematics. Some of the modules of this type, which have been developed or tested for nine undergraduate mathematics courses at Florida State University, are titled as follows:

Course	Topics
Differential Calculus	1) Critical values & graphs using derivative values. 2) Newton's method for root approximation.
Integral Cal.	1) Integral as the limit of a sum. 2) Approximate numerical evaluation for definite integrals.
Numerical Calculus	1) Solutions for f(x) = x. 2) Curve fitting with polynomials.
Infinite Series	1) Convergent and divergent series or sequences.
Mathematical Modelling	1) Soln. of the discrete logistic eq. 2) Predator/Prey models. 3) Age structured population growth.
Differential Equations	1) Direction fields and numerical solutions; y' = f(x,y). 2) Graphical displays for solutions of second order linear equations with constant coefficients.
Fourier Series	1) Graphical displays of Fourier Series, partial sum convergence. 2) Discrete Fourier Series.
Complex Variables	1) Complex arithmetic and mappings. 2) Dynamic illustrations of conformal mapping.
Partial Differential Equations	1) The DIRICHLET problem for the LaPlace equation on a rectangle. 2) Initial boundary problem for a parabolic equation.

It appears to the author that a major factor in slowing the spread of computer use in mathematics instruction has been the drastic cutback of the National Science Foundation education funds and programs over the past eight years. National curricular efforts such as CUPM and SMSG have been completely eliminated. Furthermore, phased-out programs at the college level, such as faculty institutes, workshops, and seminars, which can help disseminate the desirable material developed under funded local projects need to be restored. The Conference Board of Mathematical Sciences and the Council of Scientific Society Presidents have expressed concern with the funding situation for Science Education with respect to the above items. Consequently, both organizations have told the National Science Foundation, the National Science Board, the Presidential Science Advisor, and Congressional leaders of the need to reverse those negative trends in science education which are inhibiting progress in science and mathematics education across the board. It is hoped this will lead to a resumption of badly needed efforts to update existing faculty on topics, such as computing, which should be reflected in their instructional activity.

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