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ABSTRACT

Clemson University's Revitalized Undergraduate Mathematics with Symbol Manipulating Graphics Calculators Project introduced Hewlett-Packard HP-48S graphing calculators into undergraduate mathematics instruction to demonstrate that calculators can be effectively integrated into the undergraduate mathematics curriculum. This document reports the results of that project. The first section gives an overview of the project, identifies its purpose, and provides background information on its origins. The second section is a project description that includes information about the calculators utilized, calculator use, the courses affected by the project, participating students, class sizes, and dissemination activities. The third section provides results summarized in four areas: impact on students, impact on faculty, external impact, and an external evaluator's report. Calculators can be successfully integrated into the undergraduate mathematics curriculum in a comprehensive way and offer the advantages of portability, low cost, the ability to engage students in mathematics, and a changed testing environment. Appendices make up a majority of the report and include lists of project presentations, project publications, and summaries of student feedback from six courses. (MDH)

Revitalized Undergraduate Mathematics with Symbol Manipulating Graphics Calculators

Final Report

Cover Sheet

ED 367 532

Grantee Organization:

Clemson University
Department of Mathematical Sciences
Clemson, South Carolina 29634

Grant Number:

P116B80609

Project Dates:

Starting Date: August 1, 1988
Ending Date: July 31, 1991
Number of Months: 36

Project Director:

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Clemson, South Carolina 29634-1907
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FIPSE Program Officer:

Brian LeKander

Grant Award:

Year 1	$ 80,198
Year 2	62,031
Year 3	57,798
Total	$200,027

Summary

The project developed a comprehensive instructional program that achieved large-scale, effective integration of high-level, graphics programmable calculators into the basic mathematics courses for science and engineering undergraduates: single-variable calculus, multivariable calculus, differential equations, linear algebra and statistics. It has been a major contributing force in the steadily increasing acceptance and use of graphics calculators in undergraduate mathematics classes and has been prominently displayed within the collegiate mathematics community. It products are being implemented in a variety of post-secondary institutions.

Project Director:

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Products of the Project:

Calculator Enhancement for Introductory Statistics, Iris B. Fetta, Harcourt Brace Jovanovich/Saunders College Publishing Company, October 1991, ISBN: 092-7269

Calculator Enhancement for Linear Algebra, Donald R. LaTorre, Harcourt Brace Jovanovich/Saunders College Publishing Company, October 1991, ISBN: 092-7293

Calculator Enhancement for Single-Variable Calculus, James H. Nicholson, Harcourt Brace Jovanovich/Saunders College Publishing Company, October 1991, ISBN: 092-7285

Calculator Enhancement for Differential Equations, T.G. Proctor, Harcourt Brace Jovanovich/Saunders College Publishing Company, October 1991, ISBN: 0092-730

Calculator Enhancement for Multivariable Calculus, J.A. Reneke, Harcourt Brace Jovanovich/Saunders College Publishing Company, October 1991, ISBN: 092-7315

Executive Summary

Project Title: Revitalized Undergraduate Mathematics with Symbol Manipulating Graphics Calculators

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Department of Mathematical Sciences
Clemson, South Carolina 29634-1907

Project Director: Donald R. LaTorre
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Project Overview

The goal of the project was to develop a comprehensive program that would effectively integrate high-level programmable graphics calculators into the basic mathematics courses for science and engineering undergraduates: single-variable calculus, multivariable calculus, differential equations, linear algebra and statistics. Up till 1988, computing in undergraduate mathematics courses had been restricted to writing or using programs for numerical calculations. But the new and emerging breed of high-level calculators, represented by the Hewlett-Packard HP-28S (January 1988) and HP-48S (March 1990) gave students the power to do much more: symbolic algebra, sophisticated graphics, interactive operating modes, all in an active learning environment.

Purpose

Computing is commonplace in mathematical research and applications, but has not yet changed the character of undergraduate mathematics learning. At the freshman and sophomore levels, most work still typically consists of paper and pencil performance of mechanical algorithms–just what machines do best. Large computers have been doing "real" mathematics for years, but cost and relative scarcity have kept them out of the classroom. No more. For in January 1988, the high-level Hewlett-Packard calculators literally exploded into the marketplace. With 32 Kilobytes of programmable random access memory, graphics and symbol manipulation capabilities, students for the first time had real graphical, numerical and symbolic computing power–more power than the campus mainframes of 25 years ago–in the palms of their hands. Relatively inexpensive, portable and reliable, these units clearly offered the potential to revolutionize undergraduate mathematics instruction and learning. Thus the project was conceived in response to a need to establish that such calculators *can* be effectively integrated into the undergraduate mathematics service curriculum.

Background and Origins

The project began in the 1988-89 academic year, was comprehensive and broad-based. Specifically, we sought to design, test, implement, and disseminate innovative, calculator-based courses in the mainstream service courses in mathematics for students in science and engineering. Calculators would be loaned to students for the duration of their courses during the development phases, since it was considered inappropriate to require them to purchase their own units during periods of experimentation. Because of the unusual scope of the project, we were successful in obtaining substantial external support from Hewlett Packard. They loaned us 95 of the HP-28S units to get the project started.

Project Description

During the first two years the project designed and class tested "prototype"and "pilot" versions of each of the 6 courses. During these years, class sizes were held to 30 and calculators were loaned to students each semester for the duration of their courses, under signed Calculator Loan Agreements. Each of the prototype and pilot courses addressed the following key questions. Where is calculator use appropriate–or inappropriate–and why? What does calculator use cost in terms of time and distraction from standard material? Which topics can be more efficiently studied with calculators? What is a proper balance between calculator use and hand performance using traditional methods? Can calculators genuinely enhance conceptual understanding? Which, possibly new topics may be introduced because of the freedom provided by the calculators?

The standard departmental-wide texts were used and we basically followed the standard syllabi. But regular, often daily, use of the calculators for both classwork and homework enabled us to concentrate on geometrical and graphical aspects, focus on essential core theory and methods, encourage students' exploration and experimentation, require active, in-class participation (a natural with the calculators), provide interesting and realistic approaches, and demonstrate the advantages of technology.

However, we were not interested in adding substantial amounts of new material, or using high-level calculator routines which deliver "final answers" at the expense of involving students with the underlying mathematical processes. *We were, after all, primarily interested in increasing student interest, involvement, comprehension and retention of the course material.*

Project Results

The project was in a conspicuous position to either exert substantial national leadership–or die quietly away with minimal impact. In 1991, by almost any account, it has been a notable success, to wit: (i) large scale implementation on the Clemson campus during the 1991-92 academic year of our 6 revitalized courses: some 50 class sections (1,800 student enrollments) of calculator-enhanced courses in which every student is using his or her own supercalculator on an almost daily basis. (ii) Selection in 1990 by the Mathematical Association of America as one of ten exemplary mainstream calculus reform projects in the nation chosen for special featuring in the 1990 MAA Note No. 17, *Priming the Calculus Pump: Innovations and Resources*. (iii) The publication, in October 1991, of a series of five books by Harcourt, Brace Jovanovich and Saunders College Publishing, each authored by a principal in this FIPSE project and dealing with the appropriate pedagogical use of high-level graphics calculators in a mainstream undergraduate mathematics course. (iv) The recent award to Clemson and the Georgia Institute of Technology of a 3-year grant (NSF), a major component of which is to adapt, refine, implement and expand across the two campuses the new content, methods, programs and materials developed under this FIPSE project. (v) The conduct, in July 1991, of a national workshop at Clemson, which brought together 30 faculty from across the country for a week of intensive interaction on using the new technology to effectively enhance instruction and learning in undergraduate mathematics. (vi) The adoption of our materials by other schools, colleges and universities (e.g., Duke University, Georgia Institute of Technology, Lock Haven University, the University of South Carolina at Conway, a consortium of five New Jersey community colleges, two technical colleges in South Carolina...and a growing list of others). (vii) The publication, or pending publication, of 27 articles in an array of professional mathematical journals, conference proceedings and other professional news media describing the impact and results of this FIPSE project.(viii) Some 120 presentations at national, regional and local meetings, conferences, seminars and colloquia concerning the project.

Summary and Conclusions

The project has more than met the goals outlined in the original proposal and has been a major contributing force towards the growing widespread acceptance and use of graphics calculators in undergraduate mathematics across the country. Not only have we shown that high-level programmable graphics calculators can be effectively integrated into the undergraduate mathematics curriculum in a comprehensive way, but that they also offer special advantages not readily available with mainframe or microcomputing equipment. Advantages such as their portability, the unexpected ability to help students become engaged with mathematics on a "personal" level and, above all, their role in changing the testing environment. Changing testing is easy and natural with calculators, but difficult to do with microcomputers.

The project has been immensely successful in achieving large-scale implementation of its results on the Clemson campus. While others are struggling to get one or two class sections going, our 50 class sections are moving forward rapidly. And in that process, we are generating a new enthusiasm for the teaching, and a new approach to the learning, of mathematics by the faculty and students who are involved. Our project is clearly institutionalized, and can only get better as it matures.

The external products of the project–five books, each dealing with appropriate pedagogical uses of high-level calculators in a mainstream mathematics course, are being regarded as benchmarks by the teaching community. In addition to whatever use might be made of them in classrooms, they are helping others become aware of the enormous wealth of opportunity for the creative uses of technology at this level.

Revitalized Undergraduate Mathematics with Symbol Manipulating Graphics Calculators

Final Report

Project Overview

The goal of the project was to develop a broad-based program within a public university that would effectively integrate high-level programmable graphics calculators into the basic mathematics courses for science and engineering undergraduates: single-variable calculus, multivariable calculus, differential equations, linear algebra and statistics. Up till 1988, computing in undergraduate mathematics courses had been restricted to writing or using programs for numerical calculations. But the new and emerging breed of high-level calculators, represented by the Hewlett-Packard HP-28S (introduced in January, 1988) gave us the power to do much more: symbolic algebra, sophisticated graphics, interactive operating modes, all in a mobile, active learning environment. Thus the project was conceived in response to a need to establish that such calculators *can* be effectively integrated into the undergraduate mathematics service curriculum, and offer *special advantages* that are not readily available with mainframe or microcomputing technology.

As the sole recipient of federal funding in 1988 for incorporating calculators into the teaching and learning of mathematics, the project was in a conspicuous position to either exert substantial national leadership–or die quietly away with minimal impact. In 1991, by almost any account, it has been a notable success, to wit:

- large scale implementation on the Clemson campus during the 1991-92 academic year of our 6 revitalized courses: some 50 class sections (1,800 student enrollments) of calculator-enhanced courses in single and multivariable calculus, differential equations, linear algebra and statistics. Every student in each of these classes is using his or her own HP-48S/SX supercalculator on an almost daily basis.

- selection in 1990 by the Mathematical Association of America (MAA) as one of ten exemplary mainstream calculus reform projects in the nation chosen for special featuring in the 1990 MAA Note No. 17, *Priming the Calculus Pump: Innovations and Resources.*
- the publication, in October 1991, of a series of five books by Harcourt, Brace Jovanovich and Saunders College Publishing, each authored by a principal in this FIPSE project and dealing with the appropriate pedagogical use of high-level graphics calculators into a mainstream undergraduate mathematics course.
- the recent award to Clemson and the Georgia Institute of Technology of a 3-year grant (NSF), a major component of which is to adapt, refine, implement and expand across the two campuses the new content, methods, programs and materials developed under this FIPSE project.
- the conduct, in July 1991, of a nationally funded workshop at Clemson on our new calculator-based courses; the workshop brought together 30 faculty from across the country for a week of intensive interaction on using the new technology to effectively enhance instruction and learning in undergraduate mathematics.
- the award of additional federal funding (NSF) to conduct two such workshops on the Clemson campus during the summer of 1992.
- the adoption of our materials by other schools, colleges and universities (e.g., Duke University, Georgia Institute of Technology, Lock Haven University, the University of South Carolina at Conway, a consortium of five New Jersey community colleges, two technical colleges in South Carolina...and a growing list of others).
- the publication, or pending publication, of 27 articles in an array of professional mathematical journals, MAA Notes, conference proceedings and other professional news media describing the impact and results of this FIPSE project.

- 120 presentations at national, regional and local meetings, conferences, seminars and colloquia concerning the project. Most of these were by invitation, as opposed to routine submission by would-be contributors.

It is clear that the project has made a major impact on the Clemson campus: by the end of the 1991-92 academic year, we will have involved some 3,500 of our students and 26 of our mathematics instructors with the project activities over a 4-year period. Moreover, our work has been institutionalized into the Clemson curriculum, with plans to substantially expand the program over the next several years. Currently, the 50 class sections we are teaching with our new approach represents roughly one-half of our offerings for science and engineering undergraduates at this level. By the fall of 1993, we plan to fully integrate graphics calculator technology into our college algebra and precalculus courses (31 class sections each year with over 1,000 enrollments) and our "business" calculus courses (another 55 class sections with over 2,100 enrollments).

Purpose

The project addressed the following problem:

Computing is commonplace in mathematical research and applications, but has not yet changed the character of undergraduate mathematics learning. At the freshman and sophomore levels, most work still typically consists of paper and pencil performance of mechanical algorithms–just what machines do best. However, there is a substantial ongoing discussion concerning the role of computational devices in undergraduate mathematics courses and 1987 ushered in a growing number of calls for new approaches which effectively integrate these devices into the curriculum.

From the article, "Who Still Does Math with Paper and Pencil", by Lynn Arthur Steen, *The Chronicle of Higher Education*, October 14, 1987: "Computation has become significant for mathematics because of a major change not just in scale but in methods: the transition from numerical mathematics, the province of scientists, to symbolic and visual mathematics, the province of mathematicians. Large computers have been doing "real" mathematics for years, but cost and relative scarcity kept them out of the classroom. No more. Mathematics-speaking machines are about to sweep the campuses, embodied both as computer disks and as pocket calculators. Much as professors like to believe that education standards are set by the faculty, the ready availability of powerful computers will enable students to set new ground rules for college mathematics. Teachers will be forced to change their approach and their assignments. They will no longer be able to teach as they taught in the paper and pencil era."

Steen's 1987 article was, indeed, to the point; for in January 1988, the Hewlett-Packard HP-28S calculator literally exploded into the marketplace. With 32 Kilobytes of programmable random access memory (RAM), graphics and symbol manipulation capabilities, students for the first time had real graphical, numerical and symbolic computing power–more power than the campus mainframes of 25 years ago–in the palms of their hands. Relatively inexpensive, portable and reliable, these units clearly offered the potential to revolutionize undergraduate mathematics instruction and learning.

Before we lost the one-time chance to capture everyone's interest in the wave of curiosity that surrounded the introduction of these powerful hand-held units, the project sought to establish that graphics calculators can be effectively integrated into the undergraduate mathematics service curriculum. Otherwise, the new calculator's existence would be acknowledged with a trite comment like "button pushers never have real understanding," and the mathematical community would continue to stress the rigor of manipulation skills at the expense of students being appropriately prepared for understanding in a new world of powerful quantitative analysis.

Background and Origins.

The project actually began in the 1987-88 academic year when a half-dozen members of Clemson's faculty, recognizing the potential for the newly-released HP-28C calculator (January 1987) to revitalize instruction and learning in basic undergraduate mathematics courses, committed themselves to the task. Impressed by the high degree of student enthusiasm in an early pilot course in calculus taught by John Kenelly in 1987-88, the project director applied to the FIPSE program for funding.

Clemson's Department of Mathematical Sciences felt qualified to lead the way in the integration of new technologies, having a history of successful curriculum innovations dating back to the late 1960's. Its faculty is more than just mathematicians-- it consists of statisticians, operations research analysts, mathematics educators and computing scientists working together to present integrated programs. All too often at other universities, broad based mathematics programs are causalities in academic "turf battles." This has not been the case at Clemson and our earlier successes had been recognized in several major federal grants.

The project was comprehensive and broad-based. Specifically, we sought to design, test, implement, and disseminate innovative, calculator-based courses in single-variable calculus (two courses), multivariable calculus, differential equations, linear algebra, and statistics. These six courses are the mainstream service courses in mathematics for students in science and engineering. The design called for experimental "prototype" and "pilot" offerings of each of the six targeted courses during the first two years, followed by a larger scale introduction into the Clemson program during the third year. Calculators would be loaned to students for the duration of their courses during the prototype and pilot phases, since it was considered inappropriate to require students to purchase their own units during periods of experimentation. Because of the unusual scope of the project, we were successful in obtaining substantial external support from Hewlett Packard. They loaned us 95 of the HP-28S units to get the project started, and we convinced our local administration to purchase another 55 HP units and 30 Sharp EL-5200 units. The 150 HP units were loaned to students in the 5 courses in calculus, differential equations and linear algebra, while the 30 sharp calculators were used in statistics classes.

A project of this magnitude requires strong, effective leadership--leadership that is not only professionally competent in the classroom but also adept at "getting things done".

Fortunately, the project staff had been carefully constructed to provide this kind of expertise. The project director, Dr. Donald R. LaTorre, is Professor and Director of Undergraduate Studies in Mathematical Sciences at Clemson. Dr. T. Gilmer Proctor is Professor and Associate Head of the Department of Mathematical Sciences. And Dr. John W. Kenelly is distinguished Alumni Professor is Mathematical Sciences and well-known nationally for his leadership, especially in the College Board's Advanced Placement Program. These three individuals were able to bring a strong and dynamic element of leadership to the project, both in its development and its dissemination, by virtue of their positions and roles in Clemson's earlier curriculum reform efforts. They were joined by three others on the Clemson faculty who were strong teachers and committed to the philosophy and goals of the project.

Project Description

The project began in earnest in August 1988, and during the 1988-89 school year designed and class tested "prototype" versions of each of the 6 courses. Other than some very tentative material from Hewlett-Packard, nothing was available relative to the pedagogical use of the calculators; thus the prototype year was genuinely a bootstrapping effort. Part of the summer of 1989 was spent refining the prototype versions, and "pilot" courses were taught each semester during the 1989-90 year.

During the first two years, class sizes were held to 30 a..d 150 HP-28S calculators were loaned to students each semester for the duration of their courses, under signed Calculator Loan Agreements. Sharp EL-5200 units were loaned to students in the statistics course. One senior graduate student acted as a calculator resource person to support the multivariable calculus and differential equations courses.

Each of the prototype and pilot courses addressed the following key questions.

- Where is calculator use appropriate–or inappropriate–and why?
- What does calculator use cost in terms of time and distraction from standard material?
- Which topics can be more efficiently studied with calculators?

- What is a proper balance between calculator use and hand performance using traditional methods?
- Can calculators genuinely enhance conceptual understanding?
- Which, possibly new, topics may be introduced because of the freedom provided by the calculators?

The standard departmental-wide texts were used and we basically followed the standard syllabi. But regular, often daily, use of the calculators for both classwork and homework enabled us to

- concentrate on geometrical and graphical aspects,
- focus on essential core theory and methods,
- encourage students' exploration and experimentation,
- require active, in-class participation (a natural with the calculators),
- provide interesting and realistic approaches, and
- demonstrate the advantages of technology.

However, we were not interested in adding substantial amounts of new material, requiring significant calculator expertise, or using high-level calculator routines which deliver "final answers" at the expense of involving students with the underlying mathematical processes. *We were, after all, primarily interested in increasing student interest, involvement, comprehension and retention of the course material.*

The project quickly caught the eye of the mathematics community and during the first two years we received many requests to make presentations on our work. In 1988, the National Science Foundation began funding initiatives directed towards the reform of calculus instruction, and part of the funding in 1989 went to the Mathematical Association of America (MAA) to rapidly disseminate to the mathematical community detailed examples of calculus reform in action. This task fell to the MAA's CRAFTY committee (Calculus Reform and the First Two Years) and in August 1989, just after the start of year two of this FIPSE project, we were invited by CRAFTY to submit materials for their review. Three of our targeted courses were Calculus I, Calculus II and Multivariable Calculus, and a fourth-Differential Equations- is generally regarded as the capstone to the calculus experience. Their review of our materials led to a two-day site visit by CRAFTY in November 1989, and in early 1990 our project was chosen by CRAFTY as one of ten to receive special featuring in their MAA Note No. 17, *Priming the Calculus Pump: Innovations and Resources* (Nov 1990).

Also, during the fall semester of 1989 we were privileged to learn that Hewlett Packard planned to release its new "supercalculator" in the Spring of 1990, the HP-48SX. This would prove to be a truly amazing unit; excellent integration of graphics, numerics and symbolics, readily customized, versatile menu-driven software, 32 Kbytes RAM expandable to 288 Kbytes, serial interfacing with pc's and Macintosh's, calculator-to-calculator infrared interfacing, and high-level plug-in application cards. Collectively, these features-when combined with the inherent portability-made a strong and convincing case for using the new calculator in the mathematics courses targeted under the grant.

All students in the College of Engineering are required to take the full four-semester calculus and differential equations sequence and almost all of the students in the College of Sciences are required to take at least two of the four semesters, with Chemistry, Physics and Mathematical Sciences majors taking all four. Electrical Engineering, Computer Engineering, Computer Science, Computer Information Systems, and Mathematical Sciences majors are also required to take the linear algebra course, and assorted other majors in Engineering and Science take this course on an elective basis. To see whether Engineering and the Sciences would support a large-scale move towards the more expensive 48SX, the project director arranged for a February 1990 proprietary presentation by the R & D project manager within Hewlett Packard for the 48SX to key faculty, department heads and their deans in these two colleges. Their interest was keen and quickly spread throughout the student body once the calculator was released to the public in March 1990. Seizing upon this interest, the project advertised that the calculator-enchanced courses for 1990-91 would require either an HP-28S ($150) or an HP-48SX ($250). Even at $250, the 48SX is a bargain when compared in constant dollars to the $25 slide rule of twenty years ago which was required in many science and engineering courses.

After a summer of further refinement of the course material and preparation for professional publication in "preliminary" book form by Harcourt Brace Jovanovich, the project began its third year, 1990-91, by completely filling 17 class sections during the fall semester. To our surprise, the more expensive HP-48SX units outnumbered the older HP-28S models by 3-to-1. Campus enthusiasm was high on using graphics calculators and we easily filled another 16 sections during the spring semester. Harcourt Brace Jovanovich's publication of our 5 course supplement books was timely (we combined Calculus I and II into a single book), and for the first time our students had something more than zeroxed handouts to augment their texts.

Our class sizes were a bit large–we restricted enrollments in these courses to 43 initially, ultimately setting into class sizes of about 40. The year was accompanied by a great deal of publicity; the release of CRAFTY book in which the Clemson project appeared first (in alphabetical order), local and regional newspaper coverage, and a 5 minute regional TV interview with the project director on the NBC affiliate. We were able to respond to all of the many requests for presentations, seminars, colloquia and workshops and published several articles on our work. We also responded to requests for more substantial articles in MAA Notes form, and these will appear later in 1991 or early 1992.

The last summer of the grant, summer 1991, was devoted almost entirely to national dissemination activities. It began with Hewlett Packard mailing a two-page article by the project director, "The Impact of Supercalculators on the Teaching of Undergraduate Mathematics at Clemson University", to the more than 31, 000 North American members of the MAA and AMS (American Mathematical Society). We then responded to a request from the American Association of Engineering Education (ASEE) by making a 1 1/2 hour presentation to their national meeting on June 17. On July 22-26, 1991 we conducted a national, week long residential workshop in Clemson for 30 mathematics faculty from across the nation. The workshop was supported by NSF funding and was designed to prepare faculty to teach contemporary revisions of core mathematics courses using calculator technology and materials developed under this FIPSE grant. We have been asked to repeat this highly successful workshop again next summer, and have been notified that we will be funded to do so. As a spin-off from the workshop, the project director has accepted an invitation to conduct a two-day workshop in Monterrey, Mexico in late November 1991. The workshop will explain the Clemson program developed under this FIPSE grant to participants assembled from throughout Mexico and several South American countries.

The grant period expired on July 31, 1991, but it is of interest to touch briefly on what is currently taking place on the Clemson campus. We have abandoned our use of the HP-28S altogether because of the appearance in June 1991 of the HP-48S. The 48S is functionally the same as the 48SX, the only difference being that the 48S – unlike the 48SX – cannot accept plug-in memory expansion cards (the "X" stands for eXpandable). It also sells on our campus for about $175. Except for an engineering student who wishes to insert a high-level application card (e.g., a mechanical engineering card), or a chemistry student who wishes to insert a chemistry card (complete with periodic table in spreadsheet format and capable of molecular weight calculations), the 48S is perfectly adequate. After all, if the 32K RAM of user memory fills up, it is a simple matter to transfer any unused data, programs, etc. to a $1.50 microcomputer disk by serial transmission with a p.c. or Macintosh. This can later be downloaded to the calculator if needed.

We are currently teaching 30 class sections of our calculator enhanced courses during the 1991 fall semester, and are planning on another 20 classes in the 1992 spring term. Although we still use standard texts for both calculator enhanced and non-calculator versions of our courses, the pervasive use of technology on our campus has led us to adopt new books in almost all of our courses. We are also using the newly published "first edition" of our 5 course supplement books, and are heavily engaged in national dissemination activities which are detailed elsewhere in this report.

Project Results

The results of the project will be summarized in four areas: Impact on Students, Impact on Faculty, External Impact, and External Evaluator's Report.

Impact on Students

First of all, we have no objective "measures" of the student learning that has taken place under the project, that is, traditional measures such as performances on common exams given to students involved in the project vis-a-vis a control group. It is practically impossible to match student groups in terms of overall mathematical backgrounds, abilities, skill levels, attitudes and learning styles. During the prototype and pilot phases, the students who participated in the project were those who, for whatever reason, happened to be enrolled in the class sections targeted for calculator enhancement and these sections were not identified to students ahead of time as being anything special. During the third year of the project, the students who participated were those who consciously chose to enroll in class sections that were advertised as being special calculator-enhanced classes that would require each student to purchase the appropriate calculator. More than anything else, regular and systematic use of the calculators throughout the conduct of our courses *has changed not only what and how we teach, but also what and how we test.* We allow free use of the devices on our tests, and part of the learning process is to determine just when, and when not, to use them. There is plenty of room for both theoretical questioning as well as more computational questioning, and we have been unable to obtain this level of testing in a more computationally restricted environment. Because of all of this, we have not considered it feasible to compare performances on common exams. It would not be fair to those taught in the "traditional" way, nor to those in our new calculator enhanced courses.

The impact of the calculators has been noticeable and overwhelmingly positive. When every student is equipped with his or her own calculator, they use it almost daily for homework and classwork, there is immediate feedback, and a strong element of participation and interaction.

A new dynamics has been introduced into the classroom and the learning process. In calculus, the real benefit of the HP's has been to encourage our students to learn–and our faculty to teach–the concepts and methods in a more *active, constructive environment from analytical, graphical and numerical perspectives.* The effective integration of the graphical and numerical solve features of the 48SX have proven to be especially beneficial in helping students to establish, for themselves, important visual and numerical connections to the analytic presentations which are characteristic of most textual material. With the calculators, students generally seem to be more involved in thinking about the material, and when they are able to effectively use these devices to help achieve a desired result, they often exhibit a strong sense of "personal ownership" of that result. Indeed, it may well be the highly personalized nature of the HP's which, in addition to their portability, makes them so attractive. Students see them as especially applicable to their needs for they work equally well in hallways, in the library, at park benches and lab benches, and are a constant companion in their backpacks. They need not confine their explorations to central facilities nor spend a lot of money on a computer. There is a genuine aura of excitement surrounding their use, which can only be interpreted in a positive sense.

In statistics, more emphasis is placed on graphing, less emphasis is given to routine computation and students obtain experience with hands-on simulation. Due to the ease with which statistical graphs are constructed and by using the programming features of the calculators, we have found that most students will explore with values different from those given in the textbook examples. Freed from tedious and time-consuming statistical calculations, they focus better on the fundamental concepts. Routine practice exercises are supplemented with realistic problems and class projects that encourage exploration and experimentation. Frequent "what ifs" are heard from students and their emerging understanding of the material becomes apparent.

But, it is in the differential equations and linear algebra courses that the 48SX units have dramatically changed the nature of things. In differential equations the calculators are used almost daily to produce graphs of solutions and to do numerical computations which are impractical by hand. Graphs of solutions especially enhance student understanding by directing attention to such characteristics as asymptotic behavior and sensitivity to changes in parameters. Solutions to alternative models are also compared graphically and then used as a basis for discussion on the appropriateness of the models. As a computational device, the HP's enable students to identify appropriate problem parameters from observed data and to study the limiting behavior of both discrete and dynamical systems. The rapid determination of eigenvalues and eigenvectors and the solution to systems of linear differential equations permits a much deeper study of such systems in the limited time available.

The calculators enhance linear algebra primarily by removing the computational burden usually associated with hand performance of matrix algorithms, thus allowing beginning students to focus more clearly on the underlying concepts and theory. We are careful not to use programs which present final results at the expense of the students becoming involved with the underlying mathematical processes, and generally, the programs are interactive requiring input and control at key steps. Thus, for example, our Gaussian elimination routine requires that the students decide when and where to pivot, and which row interchanges are needed. Although we are not concerned with introducing a substantial amount of new material into the course, the HP's have enabled us to achieve good results with two modern topics which are often omitted in previous offerings: the interpretation of Gaussian elimination as an LU-factorization and its application to linear systems with multiple right-hand sides, and the interpretation of the Gram-Schmidt process as a QR-factorization and its application to least squares problems. These topics are important today because they lie close to the heart of many computer codes used to handle large linear systems.

Do students learn more mathematics? Do they better understand what they learn? These are tough questions, questions which we are unable to answer with any strong sense of accuracy. But our students have certainly seen mathematics in a different light, have clearly shown us that they can grasp some of the concepts better than before, and to the extent that they are all more interested and involved in their learning we see this as a positive effect. They are genuinely complimentary in their assessment of the role of calculators.

Impact on Faculty

In order to effectively incorporate calculators into undergraduate mathematics it soon became apparent to the faculty involved that we must do two things.

(i) Change the role of the instructor from being the traditional "lecturer" who transmits knowledge to students to more of a professional "guide"; someone who may lecture at various times but most often explains, questions, challenges and in a variety of other ways helps students become *engaged* with the course material.

(ii) Relinquish our hold on the traditional controlled classroom atmosphere characterized by "teachers prescribe...students transcribe", in favor of a more unstructured environment in which *students themselves become the more active participants.*

In short, our time-honored method of "lecturing" to our classes had to give way to other, more constructive arenas for learning. This has been, at times, a painful experience for us because change in the classroom does not come easily to most mathematics faculty. The very thought of teaching in a more unstructured setting wherein the teacher is to, somehow, engage students with the material is threatening to some. It means, for instance, that faculty can no longer be the authoritarian purveyors of knowledge and must rethink, very carefully, not only what they will do but how and why it should be done. In almost every case, the faculty who became involved in the project were able to make the necessary adjustments. In doing so, they experienced, for the first time, what current research tells us about how students learn mathematics. Students learn best when they construct their own personal interpretations of concepts by making the necessary connections and having a stake in their learning; they learn little in the passive process of "being told", and usually fail to establish the connections which ultimately lead to the assimilation of knowledge as something personal.

We have found that class attendance in the calculator enhanced classes is dramatically improved, and most of these classes develop a sense of unity brought on by the joint explorations and discussions of students and their teachers in the more personal, dynamic environment created by the calculators.

The project has had an unexpected impact on the departmental faculty: it has generated a renewed interest in, and enthusiasm for, good teaching and the pedagogical issues surrounding the good teaching of the affected courses. In the 1990-91 academic year, we conducted a weekly "support" seminar for the 15 instructors who were teaching in the project. That seminar proved to be a lively and often spirited forum for the exchange of ideas, opinions, student activities and projects, what was working well in the classroom and what was not. Most significantly, it was the *first* such seminar devoted to teaching issues conducted within the department in over 20 years. We have expanded it considerably during the 1991-92 academic year for the 22 instructors in the project and are conducting *three* seminars each week, one for each of the single-variable calculus, multivariable calculus and differential equations courses.

External Impact

The project has been a major contributing force towards the growing widespread acceptance and use of graphics calculators in undergraduate mathematics across the country. At the project's outset, several in national leadership positions clearly recognized the potential of those devices to help change the nature of instruction and learning. (See, e.g., the article by Lynn Steen cited on p.3.) But no one had first-hand experience with using them in mathematics classrooms and there were many unanswered questions. There were also numerous skeptics who, though they regarded microcomputers as worthwhile and acceptable products of technology to help students learn, regarded hand-held calculators–no matter how sophisticated–as an "inappropriate intellectual crutch". We are not surprised that there are skeptics, simply because none of us was brought up in an era in which technology was readily available to be used as a tool to help us learn when needed. But their ranks are thinning; we have seen this not only on our own campus but in places across the country where we have made presentations.

Since the beginning of our second year, the principal leaders in the project have been articulate and persistent spokespersons for the incorporation of calculators into our nation's mathematics classrooms, and our lists of presentations are impressive: Some 120 presentations during the 3-year period of the grant, with another 14 scheduled to take place by January 1992.

The selection of the project by the MAA's CRAFTY committee in early 1990 as one of ten exemplary reform projects in the nation, the timely publication by Harcourt Brace Jovanovich in August 1990 of preliminary editions of our 5 books on the incorporation of calculator technology into mainstream courses in mathematics, our invited presentations for three years at one of the nation's foremost conferences, "The Annual International Conference on Technology in Collegiate Mathematics," our effective partnership with Hewlett-Packard which resulted in their publicizing the impact of our project to over 31,000 professionals in the mathematics community last Spring, and our growing list of publications (23 to date and another 4 accepted for publication), all combine to produce a significant national impact. Two from this project (Kenelly and LaTorre) also serve on the advisory board of the only major calculator project to receive NSF funding (1989), and we are often called upon by high schools to assist with their implementations of calculators at the secondary level. It is also interesting to note that the NSF has just announced its 1991 Calculus Awards (UME Trends, October 1991) and five of the nineteen awards, over 25%, have graphics calculator components. The large-scale implementation of our project on the Clemson campus has not gone unnoticed; others are already in the process of incorporating our work onto their campuses (e.g., see the third and sixth bullets on p. 2).

External Evaluator's Report

The external evaluation has followed the project throughout the duration of the project. During the development phase we interviewed students and project staff involved in the prototype classes. We observed classes and we examined project materials -- course syllabi, handouts, and tests. We were also able to sense the atmosphere at Clemson with regard to these experimental courses. Subsequently, we developed an instrument to obtain feedback from students at the end of each course. Midway through the project we observed classes and met with students in the courses. At the end of the project we had additional interviews with students currently or previously in the calculator based courses.

During the development phase we found student enthusiasm and project staff commitment to the prototype courses to be very positive. There were concerns, but there was an underlying belief that the graphics calculators could be used to help develop better mathematical experiences for students. There were management problems. Students expressed concerns for being able to schedule a calculator section for whatever course was next in their studies. There were concerns for whether the calculator and noncalculator sections covered the same material: "Will I learn as much calculus in the calculator section as my friends will in the non-calculator sections?" There were criticisms from the students that taking a calculator based course was like taking two courses.

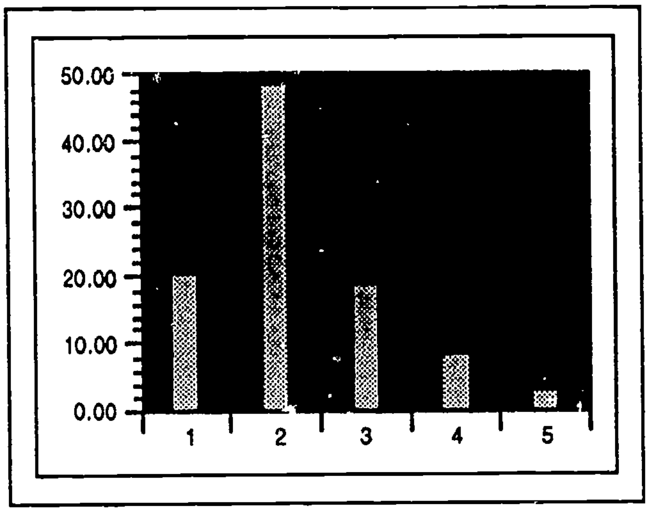
The project staff had the endorsement of the administration at Clemson but less than full support from among their mathematics colleagues. One success of this project is the acceptance of the project by a significant majority of the mathematics faculty as the calculator sections went from 6 in 1988-89 (Prototypes), to 6 in 1989-90, to 33 in 1990-91, to 50 in 1991-92. The post-project continuation and expansion of the project is dramatic evidence of the success of the project. Clearly, the project could not expand to this extent without the involvement of faculty beyond the project staff. Through the four years, Clemson will deliver calculator based instruction to approximately 3500 students as a result of this project.

We obtained feedback from 39 classes involving 969 students during the operation of the project. A questionnaire was developed to assess the students' perceptions of the use of calculators. There were 18 statements that asked the students to respond to one of five levels from strongly agree to strongly disagree. Each of these statements dealt with some aspect of using graphing calculators in calculus, differential equations, statistics, or linear algebra. There were also questions asking for open-ended response to "What did you like best?", "What did you like least?", and "Give an example of a problem that you have solved using the calculator that someone without a calculator probably could not do."

The appendix has one selected summary for a section from each of the six courses in the project. We feel these six summaries are representative of the total package of 39 sections. In this section we will present the results on selected questions from the instrument.

A central theme of mathematics instruction in the project was an emphasis on understanding the mathematics being studied. A statement about understanding is given below with the percent of students' responses for strongly agree, agree, neutral, disagree, and strongly disagree shown, left to right in the chart. These instruments were completed by the students at the end of each course.

The graphics calculator helped me understand the material in the course.



SA	A	N	D	SD
20.85	49.02	18.68	8.57	2.99

Approximately 70 percent for the students across all experimental courses felt the graphics calculator helped them understand the material. A similar graph for the MthSc 106 (First course in Calculus) with data from 8 courses involving 217 students produced essentially the same percentages. Thus the positive perceptions were as likely from beginning students as they were from more advanced students. The development of understanding was a key objective of this project. Follow-up responses, both written and oral, provided extensive documentation of the reasons students felt the calculator helped them understand the material. Among the more frequent categories of statements were

a. being able to obtain graphs quickly and accurately

b. trying several graphs; figuring out things from the graphs

c. ease of computations; accuracy of computations

d. matrix computations

e. visualizing (you could "see" mathematical relations)

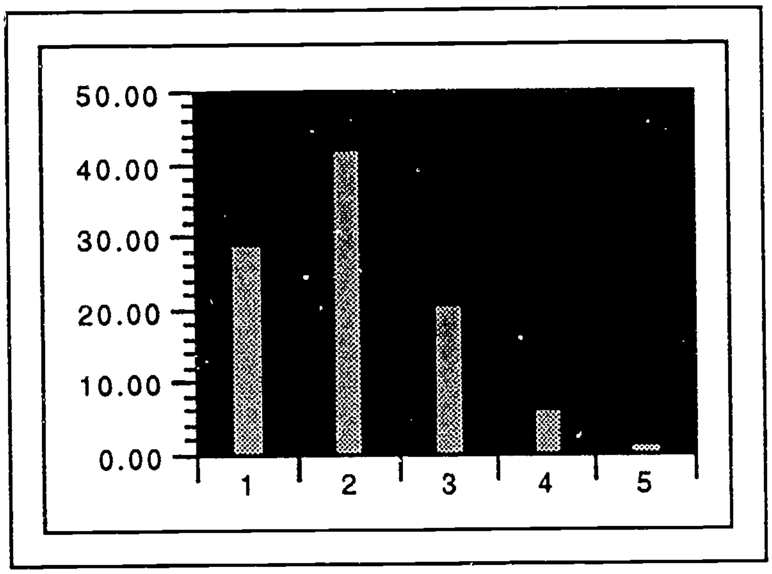
f. made graphs easier to understand; more useful

In addition to this result, we were able to obtain considerable confirmation, through questionnaires and oral interviews, that the students in these classes understood and could use mathematics.

Over 91 percent of the students strongly agreed or agreed with a statement that the graphics calculator was useful in solving problems in these courses. In many classes 100 percent agreed or strongly agreed. It was clear that students were responding to ease and accuracy of calculations in doing the problems as well as being able to approach more difficult or more realistic problems. A considerable smaller percentage of students, but still a majority of them, felt the calculator was necessary in solving problems. The facility to store programs and recall them for working on complex problems was mentioned quite often by students as a means to enhance the calculator's capability as a problem solving tool.

Exploration and investigation are desirable aspects of a dynamic, process oriented approach to mathematics. The project staff felt that using calculators with appropriate questions and problems would facilitate these traits. One item was designed to see if students sensed an opportunity for exploration and investigation at the end of a calculator based course.

The graphics calculator allowed me to do more exploration and investigation in solving problems.



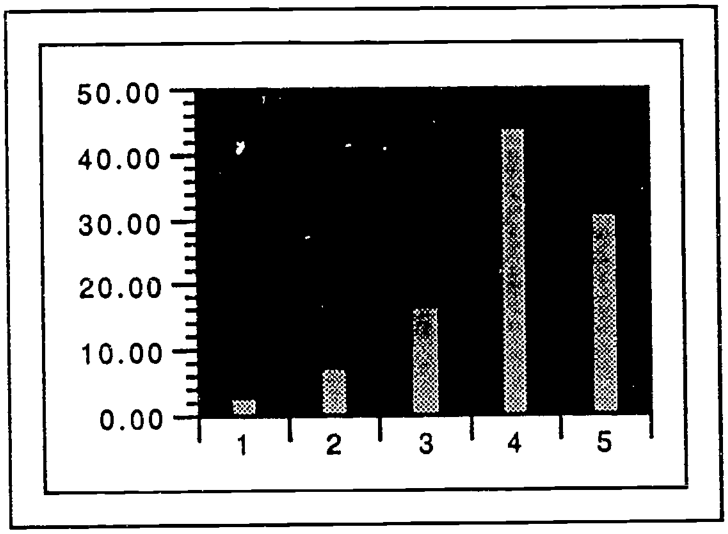
SA	A	N	D	SD
28.82	41.94	20.56	6.20	1.55

This indicates that over 70 percent of the students across all classes sensed an opportunity for exploration and investigation. These are not characteristics generally associated with the study of lower division undergraduate mathematics. The results are even more remarkable in that another 20 percent of the students were neutral and only about 8 percent would have explicitly disagreed with describing their calculator based mathematics instruction to have exploration and investigation. Comments throughout the openended responses and in the interviews underscored this result. Some typical comments were:

- "One could evaluate several different possibilities for each problem . . ."
- "You could see what a graph should look like just to see if you have the right idea."

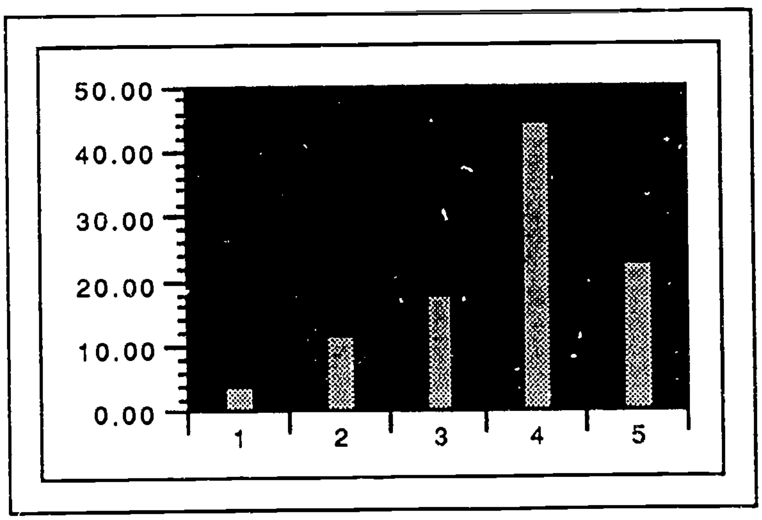
There are perceptions held by some people that using the calculator with these courses would be detrimental because of attention or time given to the calculator rather than the substance of the course. The following two items dealt with these issues:

Learning the graphics calculator was so difficult that it detracted from learning the material in the course



SA	A	N	D	SD
2.69	7.13	16.53	43.90	30.58

Time devoted to instruction in the use of the graphics calculator meant less material was covered in the course

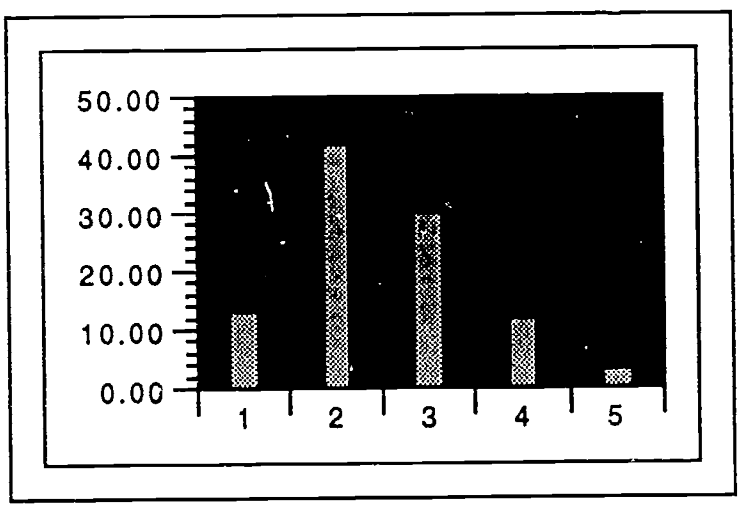


SA	A	N	D	SD
3.62	11.67	17.87	44.52	22.62

It is clear that the majority of students in these courses disagreed with these statements. That is, students did not feel that using the graphics calculator shortchanged them in terms of their course content. Many of the openended responses pointedly addressed that the calculator based courses demanded extra effort and extra time. In the interviews, a frequent theme was to hope for some way to be found to ease the strain of learning to use the calculator (e.g., special seminars, graduate assistants, or handouts). We found students who were concerned about the coverage of material before taking the courses. At the end of the courses almost all students felt they had covered more material than friends in non-calculator courses.

Intuition about mathematics is rather intangible but related to a feeling of understanding and confidence in doing mathematics. The following statement examined the students' perception of their mathematical intuition:

The graphics calculator helps me have a better intuition about the material.



SA	A	N	D	SD
13.11	41.90	29.93	11.87	2.99

Here again, a majority of the students would agree or strongly agree with the statement. In the student interviews, students who were successful with the calculator (and almost all were) were very confident in their knowledge of mathematics.

We asked the students to give an example of a problem they had solved using a graphics calculator that someone without a calculator would not have been able to do. In part, their responses, taken for a whole class rather than for individual students, provided some evidence of the power. Many responses were just complicated computations (e.g.

evaluating a 6 by 6 determinant, evaluating triple integrals). Over the duration of the project, however, we have found that some students did grasp that the calculator opened up new topics in mathematics to them, and, in the later stages of the project, we have seen more challenging problems indicated by the students.

Another result of the project is the developm`, review, and publication of calculator-based texts for these courses. Clearly, accomplishing this required time and support beyond the project, but perhaps the stimulus came from an early realization by the staff that their original goal of integrating calculators into the undergraduate mathematics service curriculum had to be changed to one of modifying that curriculum and -- as they have documented --- changing the way these courses are taught.

The most powerful result of this project may be the staff's observations and conclusions about how student learning is fundamentally changed by the effective integration of graphics calculators. That is, they have observed a sort of empowerment of the students to use the calculator to go about *constructing mathematics from analytical, graphical, and numerical perspectives.* In particular, they have observed that students develop strategies to generate, manipulate, and use visual images relevant to their mathematics. In the past, visualizations have been largely a *product* of students' mathematics rather than a process used to develop mathematical ideas. There is a need for research on this topic and the Clemson environment is one where a useful and productive research program on the learning of mathematics should be mounted.

Persistent concerns have been with us throughout the project. These include

• Time to learn to use the calculator. Many students have indicated some aspect of this as "liked least" about the course. For the neophyte, the HP-28S or the HP-48SX are formidable. Students have suggested special courses, help sessions, worksheets, etc.

• The difficulty of learning to use these calculators. Students cite the poor quality of the manuals, the use of RPN, and the complexity of the machines. In general, many students have difficulty learning to use these machines "on their own."

• The feeling that one must learn the basics "by hand" before moving on to using the calculator. For example, some students in the interviews were in multivariable calculus (MthSc 206) or differential equations (MthSc 208). They were enthusiastic about the use of the calculator and insightful in their descriptions of the benefits they derived from studying mathematics in a calculator enhanced environment. Yet, they argued that perhaps it was not appropriate to use the calculator in beginning calculus since those basics had to be learned without the calculator. Faculty have tended to be very conservative on this point.

• There is a belief by some students that they will come to rely too much on the calculator.

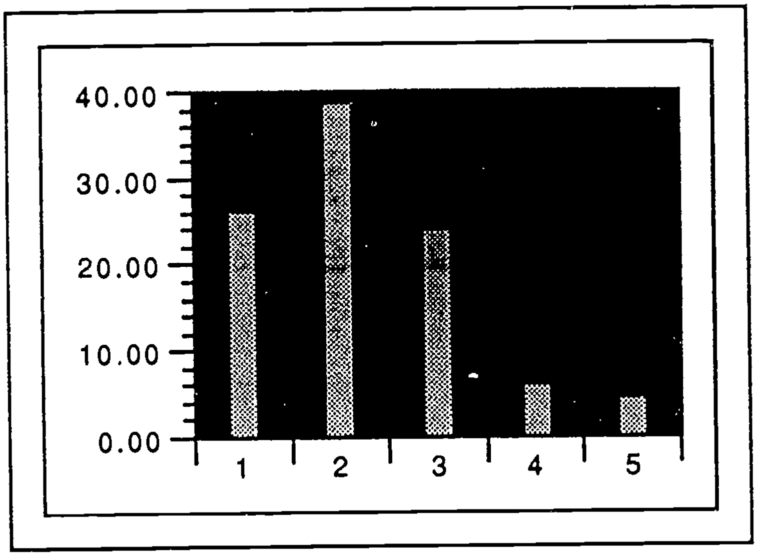
Interviews were held with approximately 15 students at the end of the project. Some of them had taken two, three, or four calculator based courses. Some were in their first calculator based course (not necessarily their first mathematics course) and three had served as tutors of students in the calculator based courses (to assist with learning the calculator). Two students expressed the intention to select their next mathematics course from a non-calculator format because the calculator based course took too much time, the tests were too difficult, or the calculator courses covered more difficult material. These "reasons" probably have merit only because the students have not progressed well enough with the calculator to really take advantage of its power.

The students identified another impact of the FIPSE project that we had not previously identified. That is, as the HP-48SX and HP-48S have been made available on campus, primarily through the impetus of this project, the use of the graphics calculator has spread rapidly to other units on campus -- such as electrical engineering, chemistry, physics, and civil engineering. We do not have other data to document this impact, but the students in the interview session had many examples of use of the HP -48SX in other classes, of professors structuring lectures and demonstrations with the HP-48SX, and of uses outside of class. Some of the students were maintaining extensive libraries on their calculator units.

It is clear that the first systematic use of the HP-48SX calculator was in the mathematics department and that its use has spread rapidly to other areas of the university.

Finally, students responded to the following question:

I would recommend that entering freshmen seek out courses using the graphics calculator.



SA	A	N	D	SD
26.32	38.80	24.05	6.19	4.54

This endorsement of the calculator based mathematics program by the people most able to take issue with it -- the students at the end of their courses -- is reflected in the demand for more calculator sections of the courses than available staff resources can handle.

We will close this section with an informal assessment of the payoff that has come from the investment of FIPSE funds in this project. The leverage from this investment is truly outstanding. One asks "What is the impact of this work?"

•Through the termination year, 3500 students will have received calculus, differential equations, linear algebra, or statistics instruction via graphics calculator enhanced instruction.

•Clemson University is committed to and has demonstrated continuing this instruction after the funding ends. The FIPSE funding has facilitated positive institutional change.

•The project staff have made over 120 presentations to professional meetings, seminars, and workshops. They had thus had impact on the use of the calculator in undergraduate mathematics instruction on a national level.

•Publications of material about the project and publications written by project staff have projected the Mathematics Department at Clemson into a national role for model programs in graphics calculator enhanced instruction. Although work is being done at many places to use graphics calculators in calculus instruction, Clemson is the only location with programs for graphics calculator instruction in differential equations and in linear algebra.

•The materials for these six course are being published by Harcourt, Brace & Jovanovich. Thus additional dissemination and impact of the project will continue through these materials.

•The Mathematics Department at Clemson University is committed to continued innovations and study of the undergraduate mathematics instruction. Funding for computer integration and support in calculus instruction has been sought. Plans to seek funding for other innovations are being pursued.

•This project brought the HP-48SX to the Clemson campus and has been a catalyst for expansion of its use in other program areas.

The impact _is_ extensive and of high quality. It is local, regional, and national. Further, there is evidence that the impact will continue at all these levels even though funding does not. The payoff from this FIPSE grant has exceeded any expectations generated at the time of funding the project.

Summary and Conclusions

The project has more than met the goals outlined in the original proposal. Not only have we shown that high-level programmable graphics calculators can be effectively integrated into the undergraduate mathematics curriculum in a comprehensive way, but that they also offer special advantages not readily available with mainframe or microcomputing equipment. Advantages such as their portability, low cost, the unexpected ability to help students become engaged with mathematics on a "personal" level and, above all, their role in changing the testing environment. With technology, it is mandatory that we change our testing, because if students sense that our tests do not accurately reflect what we do on a daily basis they will quickly cut back on their efforts. Changing testing is easy and natural with calculators, but difficult to do with microcomputers.

The project has been immensely successful in achieving large-scale implementation of its results on the Clemson campus. While others are struggling to get one or two class sections going, our 50 class sections are moving forward rapidly. And in that process, we are generating a new enthusiasm for the teaching, and a new approach to the learning, of mathematics by the faculty and students who are involved. Student reactions to calculator use are well-documented in the report by our external evaluator, and they are overwhelmingly positive. Unfortunately, we have neglected to systematically ascertain changing faculty attitudes, but more than a few have commented that they cannot conceive of teaching *without* calculators again. Our project is clearly institutionalized, and can only get better as it matures.

The external products of the project–five books, each dealing with appropriate pedagogical uses of high-level calculators in a mainstream mathematics course, are being regarded as benchmarks by the teaching community. In addition to whatever use might be made of them in classrooms, they are helping others become aware of the enormous wealth of opportunity for the creative uses of technology at this level.

Finally, we are convinced that the impetus for change brought forth by this project is both strong and long-lasting. FIPSE can look back upon this project a decade from now with a genuine understanding and a clear realization of what it helped to accomplish.

Appendix I

Project Presentations

Presentations

Donald R. LaTorre

1. "Revitalizing Undergraduate Mathematics with Symbol Manipulating Graphics Calculators", AMS/MAA Joint Mathematics Meetings, Boulder, Colorado, August 7, 1989.

2. Invited Colloquium, "Graphing Calculators in the Mathematics Classroom", to Department of Mathematics Education, University of Georgia, September 12, 1989.

3-4. Two invited presentations (1 hr each) on "Applications of Calculator Technology in Undergraduate Mathematics", to the Second International Conference on Technology in Collegiate Mathematics, November 2-4, 1989.

5. Invited presentation to the special session on Calculus Reform, AMS/MAA Joint Mathematics Meetings, Louisville, KY, January 1990.

6. Presentation to Pickens County, S.C., Secondary Mathematics Teachers, April 2, 1990: "Graphing Calculators in the Classroom".

7-8. Two invited presentations on "Graphing Calculators in the Undergraduate Curriculum", UNC-Charlotte Mini-Conference on Graphics Calculators, Charlotte, N.C., March 24, 1990.

9-10. "Clemson's Graphics Calculator Project" and "Calculator-Based Linear Algebra", to the Southeastern Regional MAA meeting in Davidson, N.C., April 6, 1990.

11. Invited presentation, "Pedagogical Uses of the HP-48SX Calculator" (with J.W. Kenelly), a two-hour presentation at the national NCTM meeting, Salt Lake City, Utah, April 18, 1990.

12. Invited panelist on Calculus Reform at the conference, "Shaping Mathematics Education for the 21st Century", Coastal Carolina College, Conway, S.C., May 11, 1990.

13. Invited presentation, "High-Level Graphics Calculators in Undergraduate Mathematics", to the NSF Conference on Symbolic Computation, Mississippi State University, June 1990.

14. Invited week-long workshop, "Using Programmable Graphing Calculators in High School Mathematics", Charlotte, N.C., July 16-20, 1990.

15-16. Two national 4-hour MAA minicourses, "A Mathematician's introduction to the HP-48SX scientific expandable calculator for first-time users" (with J.W. Kenelly) at the MAA/AMS Joint Mathematics Meetings in Columbus, Ohio in August 1990 and in San Francisco, CA in January 1991.

17. Invited Address, "Leading Mathematics Education into the Twenty-First Century", to the South Carolina Council of Teachers of Mathematics (annual statewide meeting), Greenville, S.C., October, 1990.

18. Invited workshop, "The HP-48SX: The Cadillac of Calculators", to the South Carolina Council of Teachers of Mathematics (annual statewide meeting), October, 1990.

19. Invited presentation, "Using Graphics Programmable Calculators to Enhance the Teaching and Learning of Undergraduate Mathematics", to the annual FIPSE project director's meeting in Washington, D.C., October 1990. (jointly with T.G. Proctor)

20. Invited 3-hour minicourse, "Using the HP-28S Calculator", to the Third International Conference on Technology in Collegiate Mathematics, Ohio State University, Columbus, Ohio, November 1990.

21. Invited presentation, "Calculator-Enhanced Linear Algebra," to the Third International Conference on Technology in Collegiate Mathematics, Ohio State University, Columbus, Ohio, November 1990.

22. Colloquium, "Calculators and Linear Algebra", to U.S. Military Academy, West Point, N.Y., December 1990.

23. "The Impact of Supercalculators on the Teaching of Undergraduate Mathematics", to the regional MAA meeting, Mobile AL, April 5, 1991.

24. "Using Supercalculators to Enhance Teaching and Learning of Linear Algebra", to the regional MAA meeting, Mobile AL, April 5, 1991.

25. Invited 2-hour workshop "Using the HP-48SX Supercalculator in Undergraduate Mathematics", to the annual Mathematics Symposium in Frostburg, MD, April 26, 1991.

26. Invited 3-hour minicourse, "Using the HP-48SX Supercalculator to Enhance Teaching and Learning of Mathematics", to the Southeast Regional AMATYC Conference in Atlanta, GA, May 17, 1991. (AMATYC: American Mathematical Association of Two-Year Colleges).

27. Invited two-hour calculator workshop to the Greenville County Teachers of Mathematics Association, June 10, 1991.

28. Invited 90 minute presentation, "Teaching Mathematics to Engineers in the Presence of Supercalculators", to the national ASEE (American Society for Engineering Education) meeting in New Orleans, LA, June 17, 1991.

29. A week's residential conference at Clemson, July 22-26, 1991 sponsored by the MAA Committee on Symbolic Computation. Thirty mathematics educators from across the country attended to learn about Clemson's innovative calculator enhanced mathematics curriculum. (jointly with J.W. Kenelly and T.G. Proctor)

30-31. Two-day symposium on the use of graphing calculators to advanced mathematics teachers from the Rowan-Salisbury, Cabarrus County and Kannapolis City, N.C. school systems, August 6-7, 1991.

32. Teacher in-service workshop (4 hours) to Williamsburg County, S.C. mathematics teachers, "Graphing Calculators in the Mathematics Classroom", August 13, 1991.

33-34. Two presentations, "A New Vision of School Mathematics", and a two-hour calculator workshop to the Joint Carolinas Meeting of the S.C. and N.C. Councils of Teachers of Mathematics, Charlotte, N.C., October 3-4, 1991.

John W. Kenelly

1988

1. August 7-Providence, RI-Mathematical Association of America, National Meeting Mini-Course, "Teaching Calculus with an HP-28 symbol manipulation calculator".

2. October 6-Charlotte, NC-Joint NCCTM/SCCTM Meeting-Invited talk, "An Overhead Projector Demo of Graphing Calculators".

3. October 24-Minneapolis, MI-NSF Leadership Conference for Calculus Project Program Directors-Organizer and Presenter.

4. October 29-Columbus, OH-Conference on Technology in Collegiate Mathematics "Calculus, Technology, NSF and the Future".

5. November 3,4-Clearwater Beach, FL-Florida Department of Education Symposium on Intensive Teacher Training-"Effectively Using Calculators in the mathematics classroom".

6. November 5- Dekalb, IL-National Center for Research in Mathematics Education's Conference on the Potential Influences of Technology on the School Mathematics Curriculum-"Technology and the Changing Face of Mathematics".

7. December 8-Washington, DC-Conference Board of the Mathematical Sciences' Council Meeting-"Calculus Reform Programs and Projects".

1989

8-10. January 12,13-Phoenix, AZ-COMAP Banquet-"Calculus Reform"-JPBM's National Department Head Meeting-"Outside Funding for the Undergraduate Curriculum"-Contributed Paper Session Co-Organizer, "What is Happening with Calculus Revision?"

11. January 18-Tempe, AZ-Arizona State University Mathematics Colloquium-"Current State of Calculus Teaching".

12. February 3,4-Dallas, TX-College Board Advanced Placement Mathematics Conference-"AP Math and Calculators: Then, Now, and When", "The national Calculus Revolution: What is it?"

13-14. February 24/25-Biloxi, MI-Louisiana/Mississippi MAA Section Meeting-"HP-28 workshop"; "Technology and the Curriculum".

15. March 1-Statesboro, GA-University Systems Regent's Mathematics Conference-"Calculus and Computers in the Classroom: An Overview".

16. March 7-Athens, GA-University of Georgia Mathematics Education Colloquium-"An overview of the Sharp EL-5200 Graphing Calculator".

17. March 14-Athens, GA-University of Georgia Mathematics Education Colloquium-"An overview of the HP-28 Symbol Manipulating Calculator".

18-19. March 31-Hartford, CT-University of Hartford's Exxon Conference: Teaching the Mathematical Core-Keynote Address, "Technology and the Curriculum"; "Round Table" Calculus" (with Gil Strang and Ken Hoffman).

20-21. April 8-Philadelphia, PA-East PA and Delaware MAA Section Meeting-"Computer Algebra Using the HP-28's", "Panel: The Use of CAS in Undergraduate Instruction' (with Warren Page, Carl Leinbach, Gerald Porter and Paul Zorn).

22. April 13-Orlando, FL-NCTM National Meeting-"Instructional Experiences with Graphing and Symbol Manipulating Calculators".

23. April 14-Orlando FL-Mu Alpha Theta Sponsor's Breakfast-"Calculators and Mathematics Instruction".

24. April 20-Atlanta, GA-Morehouse Exxon Conference on Effective Strategies for Teaching Calculus at the College Level-"The Three Legs of Calculus" Numbers, Graphs and Symbols".

25. May 12-Holland, MI-Michigan MAA Section Meeting-"Technology and the Curriculum", "New Directions for the Calculus".

26-40. During the 1989-90 academic year, Dr. Kenelly was on leave to the College Board. During that time, he made an average of 2 presentations per week, of which roughly one-half were relative to the use of graphics calculators at Clemson under this FIPSE project.

<u>1990</u>

41. Panel Presentation, National Math Meeting, Columbus, OH August, '90.

42. NCTM, Madison, WI, October 13, 1990

43. NCTM, Parsippany, NJ, October 18, 1990

44-45. Conference on Technology in Collegiate Mathematics, Columbus, OH, November 9, 1990 and November 11, 1990.

46. University of South Carolina-Spartanburg, November 13, 1990.

1991

47. Panel Presentation, National Math Meeting, San Francisco, CA, January 17, 1991

48. Mini-Course, National Math Meetings, San Francisco, CA, January 19, 1991

49. NCTM, Sacramento, CA, February 8, 1991

50. MAA Texas Meeting, Nacogdoches, TX, April 5, 1991

51. Iowa Articulation Conference (keynote), Cedar Falls, Iowa, April, 10, 1991

52. NCSM, (keynote) New Orleans, LA, April 15, 1991

53-54 NCTM National, New Orleans, LA, April 17, 1991 and April 19, 1991

55. Mu Alpha Theta National Convention, Huntsville, AL, August 3, 1991

56. New Jersey two year College, Consortium, Union County Community College, Keniworth, New Jersey, September 21-22, 1991

T. G. Proctor

1. "Integrating Technology in Differential Equations at Clemson University" Workshop at the Second Annual Conference on Technology in Collegiate Mathematics, Ohio State University, November 4, 1989.

2. "Calculator Enhanced Mathematics: Differential Equations," Southeastern Regional MAA Meeting, Davidson College, April 6, 1990.

3. "A Calculator Enhanced Differential Equations Course," Southeastern Atlantic Section Meeting of SIAM, University of South Carolina, Aiken, S.C., April 1990.

4. "Clemson's Calculator Curriculum: Differential Equations,"Conference on Technology, San Jacinto Community College, Houston Texas, June 16, 1990.

5. "Clemson's Calculator Curriculum: Differential Equations," Workshop at the Third Annual Conference on Technology in Collegiate Mathematics, Ohio State University, November 9, 1990.

6. "Calculator Enhancement of the Differential Equations Courses at Clemson", Southeastern Regional MAA Meeting, Mobile AL, April 5, 1991.

7. "Differential Equations and the HP Family of Supercalculators", American Society for Engineering Education, 1991 Annual Meeting, June 1991, New Orleans.

8. "Computer Algebra Systems Workshop", (Sponsor: National Science Foundation), Clemson University, July 22-26, 1991 (with John Kenelly, D. R. LaTorre).

9. "Using Graphics Programmable Calculators to Enhance the Teaching and Learning of Undergraduate Mathematics", to FIPSE project directors meeting, Washington, D.C. October, 1990 (jointly with D. R. LaTorre)

Iris B. Fetta

1. Second Annual Conference on Technology in Collegiate Mathematics, Ohio State University, November, 1989: "Probability and Statistics Using the Sharp EL-5200 Graphics Calculator".

2. Colloquium speaker for the Mathematical Sciences Department of Clemson University, January, 1990: "Probability and Statistics Using the Sharp EL-5200 Graphics Calculator".

3. Copresenter with John Kenelly: "The Informed Consumer's Instructional Guide to Graphing Calculators", MAA Minicourse #17, American Mathematical Society and Mathematical Association of America Joint Meeting, January, 1990, Louisville, Kentucky.

4. "Integrating Graphing Calculators into Undergraduate Mathematics", University of North Carolina at Charlotte, March, 1990.

5. Southeastern Sectional Meeting of the Mathematics Association of America, Davidson, NC, March, 1990 "Graphing Calculator Applications to Probability and Statistics".

6. Third Annual Conference on Technology in Collegiate Mathematics, Ohio State University, November, 1990: "Probability and Statistics Using the Sharp EL-5200 Graphics Calculator".

7. South Carolina Council of Teachers of Mathematics, Greenville, SC, November 1990: Hands-On Workshop: "Classroom Applications of the TI-81 Graphing Calculator in Algebra, Precalculus and Statistics Courses".

8. "Calculator Enhanced Introductory Statistics", American Mathematical Society and Mathematical Association of America joint meeting, San Francisco, California, January, 1991.

9. Southeastern Sectional Meeting of the Mathematical Association of America, Mobile, Alabama: "Calculator Enhanced Probability and Statistics", March, 1991.

10. Regional AMATYC Conference: "Using the TI-81 Graphing Calculator in Algebra", Atlanta, Georgia, June, 1992.

11. Second Annual Texas Conference on Technology, "The Graphing Calculator and Student Attitudes", "Integrating Calculators and Computer Testing in the Clemson Project", and Panelist for "How Smart Do We Want Our Technology to Be?", Houston, Texas, June, 1991.

12. "Using the HP-48S in Statistics", Computer Algebra Systems Workshop, Clemson University, July, 1991.

13. Joint NCCTM and SCCTM Carolinas Conference, Charlotte, NC, October, 1991: "Algebra Applications for Inverse Functions, Sequences and Series using the TI-81 Graphing Calculator".

James H. Nicholson

1. Colloquium (with D.R. LaTorre), "Graphing Calculators in the Mathematics Classroom", to Department of Mathematics Education, University of Georgia, September 12, 1989.

2. Two-hour presentation (with John W. Kenelly)," HP-28S Calculator Enhanced Calculus", to the Second Annual Conference on Technology in Collegiate Mathematics, Columbus, Ohio, November 3, 1989.

3. Invited presentation, "Graphics Calculators in Single-Variable Calculus", UNC-Charlotte, March 24, 1990.

4. Two hour presentation (with John W. Kenelly), "Graphics Calculators in the Calculus Classroom", to the Third Annual Conference on Technology in Collegiate Mathematics, Columbus, Ohio, November 9, 1990.

James A. Reneke

1. Workshop: "HP-28S Enhanced Multivariable Calculus", Second Annual Conference on Technology in Collegiate Mathematics, Ohio State University, Columbus, Ohio, November 2-4, 1989.

2. "The Graphics Calculator and Polya's Problems", to the Southeastern Regional MAA meeting in Davidson, N.C., April, 1990.

3. "Clemson's Calculator Curriculum: Multivariable Calculus", Third Annual International Conference on Technology in Collegiate Mathematics, Ohio State University, Columbus, Ohio, November 9-11, 1990.

4. One hour presentation, "Multivariable Calculus on the HP-48", University of Tennessee, Knoxville, TN, April, 1991.

Scheduled Presentations

Donald R. LaTorre

1. "Using the HP-48SX Supercalculator to Enhance Teaching and Learning in Linear Algebra", to the Conference on Technology in the Mathematics Classroom, Georgia Institute of Technology, Atlanta, Georgia, November 2, 1991.

2. "The Impact of Supercalculators on the Teaching and Learning of Linear Algebra", to the Fourth Annual International Conference on Technology in Collegiate Mathematics, Portland, Oregon, November 15-17, 1991.

3. Two-hour workshop, "Linear Algebra on the HP-48" to the Fourth Annual International Conference on Technology in Collegiate Mathematics, Portland, Oregon, November 15-17, 1991.

4-5. Two-day symposium, "Using Supercalculators to Enhance Instruction and Learning in Undergraduate Mathematics", Monterrey, Mexico, November 18-19, 1991.

6-7. Two-day workshop, "Using the HP-48S/SX Supercalculator in Calculus", Gulf Coast Community College, Panama City, Florida, November 22-23, 1991.

8. MAA minicourse (with J.W. Kenelly), "Why, When and How to use CAS Calculators in Calculus and Linear Algebra Instruction", Joint Mathematics Meeting, Baltimore, Maryland, January 8-11, 1992.

John W. Kenelly

1. "Power Series on an HP-48 Shows How CAS can Change Calculus Instruction", to the Fourth Annual International Conference on Technology in Collegiate Mathematics, Portland, Oregon, November 17, 1991

T. G. Proctor

1. "Differential Equations on the HP-48", to the Fourth Annual International Conference on Technology in Collegiate Mathematics, Portland, Oregon, November 17, 1991.

Iris B. Fetta

1. Workshop: "Statistics Using the TI-81 and Sharp EL-5200 Graphing Calculators", Fourth Annual Conference on Technology in Collegiate Mathematics, Portland, Oregon, November, 1991

2. "Integrating Graphing Calculators and Computer Testing" Fourth Annual Conference on Technology in Collegiate Mathematics, Portland, Oregon, November, 1991

3. "The Power of Visualization in Algebra and Precalculus" and "Histogram Races for Introductory Business Statistics", American Mathematical Society and Mathematical Association of America Joint Meeting, Baltimore, January, 1992

4. "The Advanced Placement Examination in Calculus with a Graphing Calculator in Hand": Michigan Calculus Conference, Grand Rapids, Michigan, March, 1992

Appendix II

Project Publications

Published Papers

By the Project:

1. "Calculator-Based Calculus", MAA Notes No. 17, Priming the Calculus Pump: Innovations and Resources, Mathematical Association of America, Washington, D.C., 1990.

2. "Clemson's Revitalization Project", Proceedings of the Second Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1990.

Donald R. LaTorre

1. "HP-28S Enhanced Linear Algebra", Proceedings of the Second International Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, November, 1990.

2. "Clemson's Revitalization Project for Calculus, Mathematics Teacher 83 (No. 7), October 1990.

3. "The Role of Calculators in Linear Algebra", UME Trends, March 1991.

4. "The Impact of Supercalculators on the Teaching of Undergraduate Mathematics at Clemson University", Hewlett-Packard's Technology Newsletter, mailed to over 31,000 members of the MAA and AMS, June 1991.

5. "A Calculator Enhanced Course in Linear Algebra", Proceedings of the Third International Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, November, 1990.

John W. Kenelly

1. "Calculus, Technology, NSF and the Future", Proceedings of the Conference on on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1989.

2. "Graphing Calculators: Comparisons and Recommendations", the Computing Teacher, 1990 (jointly with F. Demana, T. Dick, J. Harvey, G. Musser and B. Waits), 1990.

3. "Using Calculators in the Standardized Testing of Mathematics", Mathematics Teacher, 83 (No.9), December 1990.

4. "Single Variable Calculus Workshop", Proceedings of the Second Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1990 (jointly with J.H. Nicholson).

5. "Calculator Enhanced Single Variable Calculus", Proceedings of the Third Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1991 (jointly with J.H. Nicholson).

T. G. Proctor

1. "Enhancement in a Differential Equations Class Using the Hewlett Packard-28S Calculator", Proceedings of the Second Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1990.

2. "Clemson's Calculator Curriculum: the Differential Equations Course", Proceedings of the Third Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1991.

Iris B. Fetta

1. Fetta, I. and J. Harvey: "Technology is Changing Tests and Testing" *UME Trends 1*, January, 1990.

2. Fetta, I., "Probability and Statistics Using the Sharp EL-5200 Graphic Calculator" *Proceedings of the Conference on Technology in Collegiate Mathematics: Teaching and Learning with Technology* (Second Annual Conference Report), Addison-Wesley, Reading, Massachusetts, November, 1990.

3. Fetta, I. and J. Kenelly, *The Informed Consumer's Instructional Guide to Graphing Calculators,* MAA Minicourse #17, American Mathematical Society and Mathematical Association of America Joint Meeting, Louisville, Kentucky, January 1990.

4. Fetta, I., "The Sharp EL-5200 Calculator: A Review" *Statistics Teacher Network*, Rose-Hulman Institute of Technology, Terre Haute, Indiana, March, 1991.

5. Fetta, I., "Graphing Calculator Enhanced Introductory Probability and Statistics" *Proceedings of the Conference on Technology in Collegiate Mathematics* (Third Annual Conference Report), Addison-Wesley, Reading, Massachusetts, November, 1991.

James H. Nicholson

1. "Single Variable Calculus Workshop", (with J.W. Kenelly), Proceedings of the Second Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1990.

2. "Calculator Enhanced Single Variable Calculus", (with J.W. Kenelly), Proceeding of the Third Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1991.

James A. Reneke

1. "HP-28S Enhanced Multivariable Calculus", Proceedings of the Second Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1990.

2. "A Calculator Enhanced Course in Multivariable Calculus", Proceedings of the Third Annual Conference on Technology in Collegiate Mathematics, Addison-Wesley, Reading, Massachusetts, 1991.

Accepted Papers

Donald R. LaTorre

1. "Using Graphics Calculators to Enhance the Teaching and Learning of Linear Algebra", to appear in an MAA Note in 1992 on Computer Algebra Systems in Undergraduate Mathematics.

T. G. Proctor

1. "Using Programmable Graphics Calculators to Enhance a Differential Equations Course", to appear in an MAA Note in 1992 on Computer Algebra Systems in Undergraduate Mathematics.

Iris B. Fetta

1. "The Use of Graphing Calculators in Introductory Statistics" *Statistics for the Twenty -First Century*, MAA Notes volume addressing curricular issues in introductory statistics, to appear, January, 1992.

2. "The HP-48SX Calculator: A Review" *Statistics Teacher Network*, Rose-Hulman Institute of Technology, Terre Haute, Indiana, to appear, 1992.

Published Books

Donald R. LaTorre

1. Calculator Enhancement for Linear Algebra, Preliminary Edition, Harcourt Brace Jovanovich, August, 1990.

2. Calculator Enhancement for Linear Algebra, HBJ/Saunders College Publishing, October, 1991.

T. G. Proctor

1. "Calculator Enhancement for Differential Equations", Preliminary Edition, Harcourt Brace Jovanovich, August 1990.

2. "Calculator Enhancement for Differential Equations", HBJ/Saunders College Publishing, October, 1991.

Iris B. Fetta

1. "Calculator Enhancement for a Course in Introductory Statistics: A Manual of Applications Using the Sharp EL-5200 Graphing Calculator", Preliminary Edition, 168 pp, Harcourt Brace Jovanovich Publishing Company, August, 1990.

James H. Nicholson

1. "Calculator Enhancement for Single-Variable Calculus", Preliminary Edition, Harcourt Brace Jovanovich, August, 1990.

2. "Calculator Enhancement for Single-Variable Calculus", HBJ/Saunders College Publishing, October, 1991.

James A. Reneke

1. "Calculator Enhancement for Multivariable Calculus", Preliminary Edition, Harcourt Brace Jovanovich, August, 1990.

2. "Calculator Enhancement for Multivariable Calculus", HBJ/Saunders College Publishing, October, 1991.

Books Pending

Iris B. Fetta

1. "Calculator Enhancement for a Course in Introductory Statistics: A Manual of Applications Using the Sharp EL-5200, Hewlett-Packard 28-S and 48S Graphing Calculators", 290 pp, Harcourt Brace Jovanovich Publishing Company, 1992

2. "Algebra, Precalculus, Statistics: A Manual of Activities for the TI-81 Graphing Calculator", Harcourt Brace Jovanovich Publishing Company, 1992

Appendix III

Sample Summaries of Student Feedback from Six Courses

MthSc 106 Calculus I

MthSc 108 Calculus II

MthSc 206 Multivariable Calculus

MthSc 208 Differential Equations

MthSc 301 Statistics

MthSc 311 Linear Algebra

(n=31)

GRAPHICS CALCULATOR PROJECT
Course: MthSc 106

SA	A	N	D	SD	NR	
5	17	6	1	2	0	1. The graphics calculator helped me understand the material in the course.
19	11	1	0	0	0	2. The graphics calculator was useful in solving problems.
4	13	10	4	0	0	3. The graphics calculator was necessary in solving problems.
13	9	8	0	1	0	4. The graphics calculator allowed me to do more exploration and investigation in solving problems.
1	2	8	15	5	0	5. Learning the graphics calculator was so difficult that it detracted from learning the material in the course.
0	2	7	17	5	0	6. Time devoted to instruction in the use of graphics calculator meant less material was covered in the course.
0	1	5	14	11	0	7. I could have learned more if I had not used a graphics calculator.
13	13	2	3	0	0	8. I have used the graphics calculator on my own for other classes.
17	10	4	0	0	0	9. Specific instructions on the use of the graphics calculator should be offered outside the course.
1	6	9	10	5	0	10. Using the graphics calculator was confusing to me.

1	6	8	12	4	0	11. The graphics calculator should be used only in advanced courses.
3	6	6	9	7	0	12. I rely too much on the graphics calculator.
11	13	3	2	2	0	13. I want to study more courses using the graphics calculator.
8	9	11	1	2	0	14. I would recommend that entering freshmen seek out courses using the graphics calculator.
4	13	6	6	2	0	15. I would recommend that high school students learn to use the graphics calculator.
1	3	3	8	16	0	16. It is unlikely that I will use the graphics calculator after this course.
5	13	8	5	0	0	17. The graphics calculator helps me have a better intuition about the material.
0	0	0	0	0	31	18. I will eventually need to purchase my own graphics calculator.

QUESTIONNAIRE

A. What did you like best about using a graphics calculator in this course?

In certain topics, it gave me a better understanding of what was going on.

Made the course my interesting and exciting.

It provides a quick way to visualize the equation being evaluated.

Simplified and reduced time spent on more complex problems.

Saves alot of time.

It's memory ability and graphics options

Makes test-taking take less time

The calculator allowed me to graph problems more accurately and graphing them consumed less time. The HP also helped with finding integrals and derivatives.

Being able to solve some of the problems on homework and tests

It simplified the material in this course

Graphing ability. Equation writing. Calculation of integrals

It made me more confident in my answers and knowing how to use it now makes me more comfortable about my engineering career.

The feasibility of solving multi-variable problems.

The calculator gives a vivid picture of the graphs. It is quicker than using your hands. It makes easier to understand difficult problems.

Always being able to see the correct answer for most every problem

I liked being able to just type in the equation and getting a answer.

The graph helped me understand the problems better. The conversions in the calculator are also very helpful

It allowed me more time to get to the nitty gritty of calc.

It gave me a method of checking my work and it also allowed me to do simple things like draw graphs. which saved some time.

Doing integrals

It aided me in test greatly. It gets rid of a lot of " busy work " while doing problems.

It was easier and took less time to graph equations and solve complex ones.

The built in functions on the HP 48sx

B. What did you like least about using a graphics calculator in this course?

Learning about how to use all of the different functions.

We didn"t use the calculator enough.

It needs a whole separate course just to learn how to use it. It a little too challenging to jump into calculus blindly, w/o knowledge of how to use the calculator.

Saved time

To work alot of the problems you need to do to much programming on the calculator. Also some of the material was taught with the calculator primarily in mind. It was taught according to how you do the problem on the calculator and not how you actually work it out.

Having to learn it.

Not knowing exactly what some of the steps using the calculator were doing

I was pretty difficult to type in the equation in an order which would be worked correctly in the calculator.

I'm afraid I might become dependent on the calculator to perform problems in the future.

It costs to much

It is not taught much in class. We were required to learn it on our own.

I now rely solely on my calculator

Nothing

All the capabilities of the calculator I really like

Not knowing enough about the calculator

The calculator could have been used more and taught a little more in depth.

I wish my instructor had a good background in using the HP-48sx

It couldn't solve many difficult equations. (not enough time for a test, anyway.)

Since I have an HP28s - I have to enter a lot of programs.

Not enough attention devoted to its use and two models in same class is confusing.

In some instances the calculator is very slow (not as slow as doing it by hand though)

It was being related well towards what we were learning. The instructors didn't show us the uses of it.

With all the material covered, we usually didn't have time to discuss the use of the calculator extensively enough.

C.Give one example of a problem you have solved using a graphics calculator that you feel someone without a calculator would not have been able to do.

Find area of region between $2y^2 = x-y$ and $x=y^2$

Some of the very difficult integration problems.

would not be solved easily w/out calculator

Everything could be done without a calculator but the calculator makes it quicker and easier.

$$f(x) = \int_0^x \sqrt{1+\sin^2 t}\, dt$$

Graph $y = (1/4\ x^{-3/8})(3x)$

For me the biggest asset was the ease in graphing

$$\int_0^2 \frac{x^2}{(x^3-4)}\, dx$$

Graphing parametric equations is much easier on the calculator than working out by hand.

Parametric equations

The graph of a parametric equation

The calculator allows you to graph many equations overlapping each other. By hand the line wouldn't be accurate enough.

I have yet to solve a problem with a calculator that I could not have done easier on my own.

I cannot recall any at this point in time.

None

D. Other comments:

Anyone can learn what buttons to push on the calculator to solve certain types of problems. I think that we should be taught to work the problems by hand and then learn how to do it on calculators. The calculator detracted from a lot of the learning. Students need to know how to do the material and understand it and not rely on the calculator. After we know how to work the material then we should be given a time saving way to do it.

I think everyone in mathmatical majors should invest in this calculator. It is a necessity in the future. I think the HP48sx is better.

Should be taught by someone who knows the calculator. not someone learning it at the same time.

There should be a separate class devoted to using the calculator where the student could also earn credit hours upon completion.

Tell HP to go to the high schools.

Need to require one model (48sx) instead of two different calculators.

I think the graphics calculators should be divided by type in various classes. (48sx in one class and the 28 in another). This would help avoid confusion. As an owner of the 48sx I found the calculator supplement book to be a complete waste of time and money.

(n=21)

GRAPHICS CALCULATOR PROJECT
Course: MthSc 108

SA	A	N	D	SD	NR	
4	13	3	1	0	0	1. The graphics calculator helped me understand the material in the course.
16	5	0	0	0	0	2. The graphics calculator was useful in solving problems.
6	10	3	2	0	0	3. The graphics calculator was necessary in solving problems.
5	12	4	0	0	0	4. The graphics calculator allowed me to do more exploration and investigation in solving problems.
0	1	1	12	7	0	5. Learning the graphics calculator was so difficult that it detracted from learning the material in the course.
0	1	0	13	7	0	6. Time devoted to instruction in the use of graphics calculator meant less material was covered in the course.
0	1	2	11	6	0	7. I could have learned more if I had not used a graphics calculator.
4	12	3	1	1	0	8. I have used the graphics calculator on my own for other classes.
4	10	5	2	0	0	9. Specific instructions on the use of the graphics calculator should be offered outside the course.
0	0	4	13	4	0	10. Using the graphics calculator was confusing to me.

0 2 3 13 3 0	11. The graphics calculator should be used only in advanced courses.
0 3 5 9 4 0	12. I rely too much on the graphics calculator.
2 12 5 1 1 0	13. I want to study more courses using the graphics calculator.
5 13 3 0 0 0	14. I would recommend that entering freshmen seek out courses using the graphics calculator.
2 9 8 2 0 0	15. I would recommend that high school students learn to use the graphics calculator.
3 2 1 2 13 0	16. It is unlikely that I will use the graphics calculator after this course.
1 12 7 1 0 0	17. The graphics calculator helps me have a better intuition about the material.
0 0 0 0 0 21	18. I will eventually need to purchase my own graphics calculator.

QUESTIONNAIRE

A. What did you like best about using a graphics calculator in this course?

It was very useful and helpful - very interesting

The graphing and derivative solver

Made calculations that would have taken hours to solve much easier

Being to see the graphs of many functions allowed to use the geometry of the functions to solve problems more easily

It helped me to see the actual graphs of functions that would be hard to visualize or draw on paper.

It helped me understand the problems better by seeing them and also helped me work them quicker

Easy to graph. You could check your answer with the calculators to see if you did it right

Helpful in longer problems and derivatives

It was fun to play with. It illustrated points well.

Being able to see graphs of equations quickly

Games that I could play and formulas that I could program

Helped me understand problems by allowing me to see function graphs

It's ability to make difficult problems easy

Helps with integration (infinite) sometimes. Graphs well and is excellent at finite integrations

I could see the graphs that I was working with. which helped me understand the problem better.

It helped me a lot with graphing, something which I know how to do, but is a very tedious task. It also helped in solving some problems.

A wider range of problems can be worked. it is useful in checking answers to simpler problems.

It helps solving some of the more difficult problems easier. and it's was a great way to check on yourself.

It solved many of the equations that were given using the ' - -
' mode

It facilitated problem-working by making it more rapid. In graphing. time was not wasting in having to draw graphs by some long method. It made tests easier to complete. & plus. you can program Blackjack & Tetris onto the calculator. It lets you get 5 pts for a graph the calculator did.

B. What did you like least about using a graphics calculator in this course?

Nothing

Learning how to use it

Didn't use it enough

Nothing

At first. learning to use it was difficult.

Because of the calculator. you had to do extra problems to go further than if you didn't have it.

Takes time to get used to it

It was very expensive but I suppose that in the long run it will be worth it

Sometimes it was confusing to figure out

Learning to use it

The awkward setup of a 28-S. Little calculator instruction seemed to be available in this course.

We didn't use the calculator enough

Having to buy such an expensive calculator and not feeling that I got $300 worth of use out of it

Not much instruction given about it in class.

We didn't explore the functions of the calculator enough.

Have to get used to Reverse Polish Notation

C. Give one example of a problem you have solved using a graphics calculator that you feel someone without a calculator would not have been able to do.

Finding the extreme points on a curve

$$\int_0^{\pi} 2\pi \sin x \sqrt{1+\cos^2 x}\, dx$$

Sum of series

Find the arc length from 1 to 4 of ln(x)

$$\int_0^{\pi} \sqrt{1+(\cos(x))^2}\, dx$$

$$\int_0^{\pi} \sqrt{1+\cos^2}\, dx$$

Graphs of sinx and cosx. much quicker than noncalc. using student

$$\int_0^{\pi} \sqrt{1+\cos^2 x}\, dx$$

Finding the extreme points on a curve

$$\int_0^{\pi} \sqrt{1+\cos^2 x}$$

I feel that with a 28S anyone can do what it has done in this course

$$\int 2\pi \cdot \sin x \cdot \sqrt{1+\cos^2 x}\, dx$$

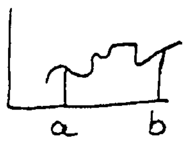
Calculating the sum of a series. Integrating problems that seem impossible.

Integrating some problems ex. $\int_0^{\pi} \sqrt{1+f'(x)}\, dx$

Many graphs. Integrals & derrivitives

$$\int_a^b 2\pi \sin x \sqrt{1+\cos^2 x}\, dx$$

Any of the graph involving sec. cot. csc



$$\int_b^a f(x)\, dx$$

D. Other comments:

None

None

The calculators could haver been used more.

Calculator enhanced classes are a marked improvement over math classes in the past.

Have the first week of class devoted to getting used to calc. and enter necessary programs for class.

The calculator is great and plus my Equation Lib. it helps me everywhere

I like the calculator

I think this calculator was great. I feel we should have a "user's group" to explore more uses for the calc.

I enjoyed the class - however. I'm not sorry that 108 fills my mathematics requirement. Nicholson is a great teacher!

(n=33)

GRAPHICS CALCULATOR PROJECT
Course: MthSc 206

SA	A	N	D	SD	NR	
10	17	4	2	0	0	1. The graphics calculator helped me understand the material in the course.
20	12	1	0	0	0	2. The graphics calculator was useful in solving problems.
4	9	14	5	1	0	3. The graphics calculator was necessary in solving problems.
7	13	12	1	0	0	4. The graphics calculator allowed me to do more exploration and investigation in solving problems.
0	2	3	16	12	0	5. Learning the graphics calculator was so difficult that it detracted from learning the material in the course.
1	3	7	11	11	0	6. Time devoted to instruction in the use of graphics calculator meant less material was covered in the course.
1	2	3	16	11	0	7. I could have learned more if I had not used a graphics calculator.
18	12	1	1	1	0	8. I have used the graphics calculator on my own for other classes.
10	14	8	0	1	0	9. Specific instructions on the use of the graphics calculator should be offered outside the course.
0	0	7	21	5	0	10. Using the graphics calculator was

0 9 8 12 4 0	11. The graphics calculator should be used only in advanced courses.
0 9 8 12 4 0	12. I rely too much on the graphics calculator.
10 14 10 0 0 0	13. I want to study more courses using the graphics calculator.
10 15 7 1 0 0	14. I would recommend that entering freshmen seek out courses using the graphics calculator.
9 11 8 2 3 0	15. I would recommend that high school students learn to use the graphics calculator.
2 0 1 9 21 0	16. It is unlikely that I will use the graphics calculator after this course.
7 13 10 2 0 1	17. The graphics calculator helps me have a better intuition about the material.
0 0 0 0 0 33	18. I will eventually need to purchase my own graphics calculator.

QUESTIONNAIRE

A. What did you like best about using a graphics calculator in this course?

It simplifies the material.

Checking your work and seeing certain graphs.

It produces a good function that I can use to solve a particular problem.

The calculator did most of the busy work of calculus for you. You have to know the principles behind calc. to even be able to analize the problem well enough to do it on the calculator.

Learning how to use the calculator in this class has allowed me to use it in other classes of similar nature. (Physics. Engineering) It is a very valuable tool - had I not purchased it for this class. I probably would not have bought it and learned its advantages.

It allowed me to check my answers on the calculator after I found a "handwritten" answer.

It helped me back up my answers.

The best thing about the graphics calculator in this course is that it would actually graph even the hardest polar coordinates.

How it plots graphs and integrates.

The graphs!

The ability to graph a difficult function and be able to see it. I also learned some computer programming while experimenting with some programs of my own.

It helped me to solve problems. It also allowed me to check my answers and see if they were correct.

It aided me in solving problems that are extremely time consuming as far as the Algabra is concern. It allowed me more time to learn the foundation of certain principals.

I could check work done by hand. It made really simple calculations faster so I could spend more time on the more complex problems.

It allowed me to focus on the theory and not get bogged down with the details of mechanics of problems.

The variety of calculations that the calculator could solve

It helped me visualize each function even if a graph was not required for the test question. It also integrated double integrals quickly and saved me a lot of hard work.

Speed of graphics. esp. helpful with polar graphs. Wide range of uses. if you have the programs and understand how to enter necessary data.

A clear illustration of polar graphs helped me better understand or detect what type of graph the equation was referring to.

Able to graph polar coordinates.

It did most of the "grunt" work which freed me up to better understand the theory of the course.

Seeing the graphed function and doing derivatives & integrals with it.

I used the graphics calculator to check answers to problems that I did by hand. I also liked using it to graph the problems so I could get an accerate picture of a figure.

The ability to graph functions. integrate functions. cross products.

Double Integrals.

It made things faster.

Help to releive monotonus work. Had more time to learn.

It helped a lot with polar coordinates. and vector algebra.

Seeing the graphs and the time saved.

You don't spend as much time trying to work out the problems after you have set them up. Saves stupid mistakes.

It's ease of graphing and integrating.

B. What did you like least about using a graphics calculator in this course?

Pr$ce.

The speed even though it is 2 MHz is quite slow in evaluating integrals.

Should have used it more!

Nothing really.

Typing in the programs for the 28S.

Nothing.

I have an HP-28S. It is less advanced than the 48-SX so I had trouble using some of the programs for the 28S.

It is too slow.

I wish there were more specific instructions and more programs.

Not knowing how to use all aspects of the calculator that would've been helpful to this course.

N/A

Programming the damn thing. HP28 should not be used unless necessary.

I didn't know how to use it with confidence.

It took up class time talking about irrelevant stuff. Plus not used enough for money spent.

Too many "beeps" going off from other students during tests.

Trying to figure it out on my own.

Sometimes the calculator was slower than I wanted.

The expense of the calculator.

Didn't use it enough for amount of money spent.

We didn't use it enough.

Programming the HP28S.

Thought we could use it more.

The professor didn't teach as well because of it.

C. Give one example of a problem you have solved using a graphics calculator that you feel someone without a calculator would not have been able to do.

Solving 4 or 5 equations at the same time.

$$\int_0^{\pi/4}\int_0^{sec} \frac{1}{sec^2}\, dydx$$

Some polar graphs and parametric curves were constructed with the calculator in half the time it would have to hand draw it.

$$\int_0^{\frac{1}{sec}}\int_0^{\cos x}\int_x^{\tan} \left(\frac{\frac{x+y}{xy + \tan\frac{2y}{x}}}{2x+1} \right) dx\, dy\, dz$$

Cross products of like $(5xi - 6yj + 3xk)(7xi - 4yj - 5zk)$

Some of the polar graphs and integrations

I don't there is a good example. But the HP can solve the problem faster, and it saves you the work.

Manipulating complex numbers when dealing with circuits.

$$\int_0^1 \int_{\ln x}^{x^2+3x} (3x^6 + 2y + 3)\, dydx$$

I had a test problem to convert rectangular double integral to polar double integral. I graphed the boundaries on my calculator- and I wouldn't have been able to graph on my own.

Any realistic engineering problem.

Double integrals with messy limits.

$$\int_0^{\pi/4}\int_0^{\sec x} \frac{\sec^2 x}{x}\, dydx$$

$$\int_2^3 \int (\sin x - \sec x)\, dydx$$

NA

Some of the polar problems and integrals would have been difficult without the calculator.

Cross product of $(10i + 11j + 12k) X (20i + 21j + 22k)$

Double integrals, polar graphs

$$(3x + 2x - 3)\, dydx$$

Double integrals, they could do it but it would take longer.

I can't think of one.

None, but some things were solved quicker.

D. Other comments:

The calculator (HP28S) was very useful in this class as well as in my other classes. It should be used from the start of one's freshman year due to its versatility.

I think more college students who are math-oriented should definitely consider the HP485X or HP28S

1 thumb up, a good course

Has blackjack too.

Looking back at Q17 of other side. I believe that further advancements can be made in various studies since the calculator takes care of the tedious work. ie understanding static, using the calc. to do Cross Prod.

4.III-2C

(n=29)

GRAPHICS CALCULATOR PROJECT
MthSc 208

SA	A	N	D	SD	NR	
4	15	6	3	0	0	1. The graphics calculator helped me understand the material in the course.
14	11	3	1	0	0	2. The graphics calculator was useful in solving problems.
3	7	13	6	0	0	3. The graphics calculator was necessary in solving problems.
9	11	4	4	1	0	4. The graphics calculator allowed me to do more exploration and investigation in solving problems.
0	3	8	9	9	0	5. Learning the graphics calculator was so difficult that it detracted from learning the material in the course.
0	3	6	13	7	0	6. Time devoted to instruction in the use of graphics calculator meant less material was covered in the course.
1	1	5	11	11	0	7. I could have learned more if I had not used a graphics calculator.
7	5	4	4	8	1	8. I have used the graphics calculator on my own for other classes.
5	11	10	3	0	0	9. Specific instructions on the use of the graphics calculator should be offered outside the course.
1	6	6	8	8	0	10. Using the graphics calculator was confusing to me.
2	6	7	6	8	0	11. The graphics calculator should be used only in advanced courses.
1	1	3	14	10	0	12. I rely too much on the graphics calculator.
7	9	5	6	2	0	13. I want to study more courses using the graphics calculator.
5	11	8	3	2	0	14. I would recommend that entering freshmen seek out courses using the graphics calculator.

5	9	8	6	1	0	15. I would recommend that high school students learn to use the graphics calculator.
4	5	2	7	11	0	16. It is unlikely that I will use the graphics calculator after this course.
5	12	4	6	2	0	17. The graphics calculator helps me have a better intuition about the material.
10	8	2	5	4	0	18. I will eventually need to purchase my own graphics calculator.

QUESTIONNAIRE

A. What did you like best about using a graphics calculator in this course?

It gave us a break from the regular teaching method (a good change). The calculator is amazing.

I am an electrical engineering student and graphical solutions are very important in gaining an understanding of circuit behavior. The actual graphical representation of a solution appealed to me the most.

You can get a picture of how your function looks, its upper and lower limits. It can be used to solve problems that I'd not be able to do on my own.

I liked graphing equations the best.

It aided in solving problems and gave an insight very quickly at how a function was responding. A must for engineers.

It did sometimes help to see what was going on in a particular problem--in terms of the graph.

Solving equations once I know how to do it and graphing capabilities.

The calculator gives excellent representations of difficult graphs.

Its ability to handle complex programs and functions with ease. Also its graphing capabilities.

Able to physically see functions. Reduced the time required to solve some problems.

Seeing the plot on the screen and finding points of in--rest --max, min, intercepts, etc.

The help in graphing functions rather than plotting them myself.

Everything!

Ease of use and better grasp of DE principles.

Graphing

How easy it was to solve for answers

I like using the calculator because it speeded up doing the problems

Graphing functions and finding max, min values

It made the material easier to complete and understand...

The graphics calculator makes it easier to solve longer problems and makes it easier to graph more complex problems.

Merely being able to graph equations and see their behavior-- useful in factoring

Being able to find roots of eqns.

It helped out with graphing and solving things for roots.

It benefited most by just using the calculator. I have my own and didn't really know how to use it, now I do.

I did not like using the thing at all.

Its power and numerable capabilities

B. What did you like least about using a graphics calculator in this course?

Finding the Pmax & Pmin. Sometimes it was frustrating trying to learn how it worked.

Nothing

I like least when it beeped at me; didn't use it much for simple addition, multiplication, etc.

Not being able to keep it when the course was over.

I just think I didn't have enough time to learn to use it fully--so I never felt very comfortable with using it--the steps involved + procedures often confused me.

The numbers come out complicated. x^3 - yx....

Never did get a good understanding of what it can do.

The calculator is too complex to learn how to use in a five week course.

Didn't get to learn enough about it.

I have too much important work in this course and my other course to fool with it.

I wish the HP 28s had better graphics

The calculator has so much potential it is difficult to move then scratch the surface in one class.

Nothing

Making mistakes

Being required to program it on tests because we were told we wouldn't have to

The FORTH programming language

At first I found the calculator to be confusing but once I understood it, it wasn't that bad. I usually have trouble graphing so it was very helpful

Spending the time learning how to use it. The course material was difficult enough.

The language and steps required are too time consuming and too difficult to relate to other languages.

The programming at first

It saved time with routine calculations of roots, etc.

A little hard to use at first.

C. Give one example of a problem you have solved using a graphics calculator that you feel someone without a calculator would not have been able to do.

Any graph.

"$\ln y = c_1 e^{-2t} + c_2 (1 - \sqrt{1+4}) + te^{3t}$

The pursuit problem with the rabbit and dog would've been a problem w/out the graphics calculator. It was interesting to see the graph "in action."

One simple example of its speed and [accuracy] is the solving of such problems as $r^3 + 3r^2 - 5r + 8 = 0$ having to be broken down into factors.

Graph " $\left(\dfrac{e^{2t} + t^2}{\sqrt{2} - e^{t^2}} \right)$

Getting the proper FN program to solve a specific problem

$r^3 - .5r^2 + 180r - 30 = 0$

I don't think there was one, but they would have taken forever to solve without the calculator

Factor " $\frac{1}{4}x^3 - \frac{7}{8}x^2 + \frac{1}{2}x + 9$"

Finding the roots of an eqn with fractional roots.

Can't think of any off the top of my head, but there are some.

Graph $x^r = e^{-3x} + x^3$

A complicated Euler problem

D. Other comments:

None

Good idea!

I truly enjoyed using the HP28s in this course. I thought it was <u>not</u> hard to learn to use. It was fun!

I would have rather been in a section that did not use it. This course is complicated enough already.

An optional course involving the use of the HP 28s in various applications would be quite helpful.

I will buy one.

I think the calculator is useful but I also don't think that it should replace the student actually learning how to do things.

I enjoyed it. I only wish they were slightly cheaper.

I think it is extremely useful for higher math classes.

None.

4.III -26

(n=24)

GRAPHICS CALCULATOR PROJECT
Course: MthSc 301

SA	A	N	D	SD	NR	
0	15	5	3	1	0	1. The graphics calculator helped me understand the material in the course.
14	9	0	0	1	0	2. The graphics calculator was useful in solving problems.
8	7	5	3	1	0	3. The graphics calculator was necessary in solving problems.
4	11	7	2	0	0	4. The graphics calculator allowed me to do more exploration and investigation in solving problems.
1	2	5	13	3	0	5. Learning the graphics calculator was so difficult that it detracted from learning the material in the course.
1	7	8	7	1	0	6. Time devoted to instruction in the use of graphics calculator meant less material was covered in the course.
2	2	6	12	2	0	7. I could have learned more if I had not used a graphics calculator.
3	9	5	1	5	0	8. I have used the graphics calculator on my own for other classes.
1	5	11	5	2	0	9. Specific instructions on the use of the graphics calculator should be offered outside the course.
1	3	3	12	5	0	10. Using the graphics calculator was confusing to me.

2 3 5 10 4 0	11. The graphics calculator should be used only in advanced courses.
1 7 7 7 2 0	12. I rely too much on the graphics calculator.
1 8 9 4 2 0	13. I want to study more courses using the graphics calculator.
0 12 8 2 2 0	14. I would recommend that entering freshmen seek out courses using the graphics calculator.
1 14 6 0 3 0	15. I would recommend that high school students learn to use the graphics calculator.
2 9 6 7 0 0	16. It is unlikely that I will use the graphics calculator after this course.
0 9 10 4 1 0	17. The graphics calculator helps me have a better intuition about the material.
1 7 8 3 5 0	18. I will eventually need to purchase my own graphics calculator.

QUESTIONNAIRE

A. What did you like best about using a graphics calculator in this course?

It saved time doing problems which allowed more time for studying.

It made the problems easier to do.

I liked using the calculator because we did not have to waste time memorizing all of the equations.

It helped cut down on the time it takes to work problems. It eliminates a lot of busy work.

The convenience of having them for tests. homework. etc.

I really was not to impressed w/ the calculators. It was shorter calculations.

I could do the problem without worrying about making little addition/subraction errors.

Not having to do all the work by hand.

Didn't have to memorize formulas.

Eliminated errors in calculating.

The calculator saved a lot of time.

It made me learn what variables were used for each formula.

The convenience of solving long, involved formulas in a short amount of time.

B. What did you like least about using a graphics calculator in this course?

Entering the programs.

The first few weeks of trying to figure out how to use it. More attention should have been given to the actual course material.

At times it was hard to remember certain keystrokes to a function.

Too much dependence. maybe not fully grasping the concepts.

The amount of programming, and the need to know how to use it.

Putting all those programs into it.

Dont always know what you're doing.

C.Give one example of a problem you have solved using a graphics calculator that you feel someone without a calculator would not have been able to do.

Two sample hypothesis testing. confidence intervals and t or z for the problem.

Simulation of a 4 coin toss with N = 50

Coin toss. Die roll. most probability formalas

Some of the problems w/ 2 populations

D. Other comments:

Enjoyed class. Good teacher.

(n=24)

GRAPHICS CALCULATOR PROJECT
MthSc 311

SA	A	N	D	SD	NR	
7	13	2	0	2	0	1. The graphics calculator helped me understand the material in the course.
21	3	0	0	0	0	2. The graphics calculator was useful in solving problems.
4	8	7	3	2	0	3. The graphics calculator was necessary in solving problems.
12	9	2	0	1	0	4. The graphics calculator allowed me to do more exploration and investigation in solving problems.
0	0	4	8	12	0	5. Learning the graphics calculator was so difficult that it detracted from learning the material in the course.
1	4	5	12	2	0	6. Time devoted to instruction in the use of graphics calculator meant less material was covered in the course.
0	0	2	10	12	0	7. I could have learned more if I had not used a graphics calculator.
10	10	0	1	3	0	8. I have used the graphics calculator on my own for other classes.
2	10	10	2	0	0	9. Specific instructions on the use of the graphics calculator should be offered outside the course.
0	1	5	6	12	0	10. Using the graphics calculator was confusing to me.
0	2	3	12	7	0	11. The graphics calculator should be used only in advanced courses.
0	1	2	16	5	0	12. I rely too much on the graphics calculator.
8	12	4	0	0	0	13. I want to study more courses using the graphics calculator.
12	10	2	0	0	0	14. I would recommend that entering freshmen seek out courses using the graphics calculator.

7	11	4	2	0	0	15. I would recommend that high school students learn to use the graphics calculator.
1	1	1	11	10	0	16. It is unlikely that I will use the graphics calculator after this course.
2	13	6	2	1	0	17. The graphics calculator helps me have a better intuition about the material.
7	9	6	1	1	0	18. I will eventually need to purchase my own graphics calculator.

QUESTIONNAIRE

A. What did you like best about using a graphics calculator in this course?

We would have spent all semester solving one large matrix if we hadn't used the HP. This way we were able to focus on the real mathematics instead of busy work.

I've always had trouble graphing and I made it much easier for me. I liked being able to see everything on the stack. It cut out all the tedious matrix multiplication.

The graphics calculator enabled the class to work problems which would arise in real situations in which the numbers don't come out integers.

It reduced all the painful equations into easy punches of the button.

Different type problems could be evaluated.

It removed all the arithmetic errors one usually gets frustrated by and allowed us to concentrate more on understanding the material. IT also made the class more like the real world where everything is done graphically and by computers.

Didn't have to spend a lot of time calculating hard numbers by hand.

It took away the mechanics of problem solving such as addition, subtraction, etc.

It makes the calculations easier so that more time can be spent on theory.

The graphics calculator allowed for quick computation of what would be lengthy, time consuming problems if done by hand. By using programs, I was able to further understand the principles behind most topics covered.

More logical, systematic way of solving problems by reducing careless errors.

It did the necessary calculations so that I could spend more time understanding the logic behind the calculations.

Made manipulation of variables in seeing how they changed outcome easier. The calculator allows a student to plow through homework faster and easier allowing time to "play" with the subject more.

The calculator takes away the "busy" work and allows time for studying the theoretical concepts.

I liked being able to solve bigger problems on less time, without having to step through it manually.

1) It allowed me the opportunity to explore variations to the assigned homework problems to see the effect of altering one of the variables in the equation.
2) I became more familiar with programming a calculator and have written programs for my other courses. If I had not taken this course I would have never taken the time out to learn to program an HP. This course stimulated my interest.

I liked being able to graph functions and solve systems of equations using the calculator and eliminating unnecessary, time-consuming algebraic operations. An example of this is using the calculator to perform Gauss-Jordan elimination.

It was amazing to see how easily the difficult problems could be worked using a calculator. After learning the hard way to solve a problem, the calculator was a breeze and didn't take up a lot of time when trying to solve problems.

The graphics calculator enabled us to solve "real world" rather than just textbook problems. The calculator was very useful in helping to eliminate a great deal of tedious arithmetic.

It allowed more time to be spent learning applications of the theory and the strategies necessary to solve matrix problems, rather than spending a lot of time doing simple math and algebra required in many problems.

B. What did you like least about using a graphics calculator in this course?

I want to be able to use it in other courses too but I rely on my old calculator--a separate course is needed for the HP.

Having to program it.

We entered programs; however, I could not program by myself. I wish we had had other courses using the calculator.

Nothing. Except that we can't keep it.

I didn't push to understand fully. I relied on the calculator to make the work easy.

Not knowing how to fully use it in relation to other courses.

Nothing the calculators made the course fun and easy to understand.

It would be more beneficial to require entering freshmen to buy one and learn how to use it in a more introductory class.

Having to return it

There were no drawbacks for me in this course.

Not enough time spent using calculator

I do not feel that I learned to use it to the fullest extent of its capabilities.

No negatives

It was difficult to understand everything I needed to know in such a short time. I wish I had had a chance to understand how to work it before the course.

That the correct procedures for its use in solving specific types of problems was presented in a hurried and confusing manner (e.g. QR Factorization). In short, it was easy to "drop behind" on some subjects in the course.

C. Give one example of a problem you have solved using a graphics calculator that you feel someone without a calculator would not have been able to do.

"

$$\det \begin{bmatrix} 10 & 11 & 12 & 13 & 14 & 51 \\ 20 & 10 & 18 & 2 & & \\ 13 & 45 & 10 & 9 & & \\ 45 & 52 & 47 & 10 & & \\ 61 & 65 & 61 & 8 & & \\ 75 & 89 & 57 & 7 & & \end{bmatrix}$$

We could do complex (difficult) problems involving matrices because the calculator did all the busy work for us and let us get on with the background, theory and real-life uses for matrices.

We used the calculator for Gaussian elimination of a matrix with numbers rounded to 10 decimals. The size of the matrix and the complexity of the calculations would have been extremely difficult without the calculator.

A matrix with many decimal numbers or on one of the projects a big 15x15 matrix.

We were able to solve more complex matrices in terms of both size and numbers.

Many of the matrix problems with imaginary and irrational numbers would be hard without the use of the calculator.

A matrix of several dimensions. A matrix of non-integer numbers

QR factorization would be real hard without the calculator, many places for error.

Pivoting on a complex entry in a matrix.

Gram Schmidt/QR Factorization could most certainly be done without it, but would be almost impossible without making careless errors.

Solving systems of equations involving 5 or more unknowns with non-textbook numbers and drawing graphs quickly.

There were no problems that could not have been done but were several that could have consumed large amounts of time.

-Matrix multiplication of large matrices
-Finding roots of polynomial of third and fourth degree.
-Finding the determinants of large matrices
-Economic models with several variables.

Any large matrix would have been too tedious to solve by hand.

Any of the systems of equations that have more than 4 variables would just be too time consuming. Or eigenvalue problems with more than 3 roots to the characteristic equation.

One example is finding the roots of a 4th degree polynomial or graphing a very difficult graph. Both would take a very long time by hand. The calculator enabled us to have more difficult problems to work in a shorter time on tests.

Linear Programming problems--input/output economics

I don't think we did any, but all the problems took less time with the calculator so more time could be spent covering the material.

D. Other comments:

The idea is fantastic. My only worry is that students will rely more and more on calculators and less on actually thinking. My parents for example can do simple math 3 or 4 times faster than I can simply because I've always had a machine to do it for me. I never had to learn all the tricks. Will my children even know how to plot a straight line?

I think that the calculator should be used in many other courses.

There needs to be a trade-off here. Most people have never touched one of these calculators and time needs to be spent on that, but the topics covered in class need to be cut down and less important ones <u>cut out</u>. This would make a better learning environment.

For our class the graphics wasn't as important as the features for solving matrices. I think the calculator is an excellent idea and it made the course easier for me.

This course should not be taken without the graphics calculator.

There should be a 1 credit elective course on how to program it. I thoroughly enjoyed using the graphics calculator and wish to purchase one for myself. Every math class should attempt to integrate the use of a graphics calculator into their curriculum.

I wish I would have had a calculator course in my freshman year. This course has greatly benefited me in my other courses.