USING COMPUTERS IN CALCULUS TEACHING

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1. INTRODUCTION

In recent years we have witnessed an increased use of technology in teaching mathematics. The current status of this process could be observed during the recent ICTCM meeting[1]. It is quite evident that this movement is wide-spread and colleges of all sizes participate in it. The aim of the present paper is twofold. First, we will address the general issue of using technology in teaching mathematics and present an overview of strategies used to support calculus teaching. Second, we will present a detailed description of one of the more interesting attempts to introduce computers into calculus teaching, the "Purdue Project."

2. USING TECHNOLOGY IN TEACHING MATHEMATICS

2.1. Overview

There is a large number of courses in the mathematics curriculum in which new technologies (based on both computers and graphing calculators) are introduced. The most typical courses include[2]:

a) pre-algebra and college algebra,
b) mathematics courses for non-majors,
c) precalculus and the calculus sequence,
d) differential equations,
e) linear algebra,
f) statistics,
g) geometry,
h) numerical analysis.

There are also some attempts to introduce computers in the teaching of:

a) discrete mathematics,
b) abstract algebra,
c) number theory.

As we can see, the main targets of the new educational technology are most of the lower and intermediate level core courses.

2.1.1 Hardware

As far as the use of technology is concerned, two general trends can be observed. The first one is the use of graphing calculators. There are several advantages of this approach.

It does not require any special computer laboratories, thus reducing the college investment costs. Lectures can be scheduled in the classrooms without blocking the computer laboratory (which is especially important if there is only one computer lab on campus). It also allows students to work on their projects/homeworks almost wherever and whenever they want. An important disadvantage of this approach, however, is that it puts a serious financial burden on the students. An average cost of a good quality graphing calculator may exceed $100. The most widely used graphing calculators are: TI-81, TI-85, Sharp EL-9200/9300, Casio 7700GB, HP-28S and HP-48SX.

The second approach is to use computers. Its advantage is that students are not burdened with additional costs. In addition, it is clear that computer based tools are more robust and flexible than those available on calculators. For example, multimedia-type environments, which integrate video, interactive text, in-class exercises and homeworks into one learning environment require computer support. Since most colleges already have (or are about to install) some kind of computer facilities, the investment on the part of colleges may not be very large[3]. There are three types of computers that are widely used to support mathematics teaching: 386/486 based PC's, Apple (Macintosh SE and up) and NeXt's.

2.1.2 Software

A large variation of software may be used in the computer-based courses. Some of the commonly used packages include:

a) Tutoring software: Algebra Tutor;
b) Spreadsheets: Lotus, PlanPerfect, EXCEL;
c) Symbolic Algebra Packages: Derive, Maple, Mathematica, MathCAD, SMP;
d) programming languages: True BASIC, Pascal;
e) special purpose languages: ISETL, cT, Matlab;
f) statistical packages: SAS, SPSS, MINITAB;
g) geometrical software: Geometrical Supposer;
h) multimedia type environments: Hypercard.

Obviously, except for the tutoring software, most of the packages do not come as "ready to use" products. The existing software tools are used to develop the learning environment.

2.2. Technology in Teaching Calculus

The National Council of Teachers of Mathematics has recently supported the use of technology in teaching calculus[4]:

> Instead of devoting large blocks of time to developing a mastery of paper-and-pencil manipulative skills, more time and effort should be spent on developing a conceptual understanding of key ideas and their applications. All students should have the benefit of a computer-enhanced introduction to some of the types of problems for which calculus was developed. [16, p. 183]

The basic aims of using computers in teaching calculus are:

- to use technology in enhancing the understanding of the concepts of calculus,
- to increase student's confidence in doing calculus,
- to illustrate and explore the ideas of calculus graphically and numerically,
- to develop student's skill of visualization,
- to make the study of calculus more enjoyable and stimulating.

There exist many approaches to the introduction of technology to the teaching of Calculus. We will try to present the most commonly used methods. In Appendix 1, we present a more detailed descriptions of a group of selected projects (also see [29]).

2.2.1. New Trends in Teaching Calculus -- an Overview

Five years ago NSF allocated a significant amount of money to support a national movement of the so-called calculus reform. At the present time, many calculus projects are undertaken throughout the United States, and the course organization varies from project to project (for more details, see [29]). Some projects combine large lecture classes with recitation sections where hand calculators are used, while others replace recitation sections with laboratory time and the use of computers and/or calculators for inducing students' conceptual grasp of calculus. The most radical projects reduce lecturing time to 10-15 minutes, or eliminate it entirely, and devote that time to students' work on assignments and discussions of concepts.

The additional component in this new methodology of teaching calculus is the use of collaborative learning in small-groups[5]. The use of groups varies from project to project. Some projects rely on "ad hoc" groups of two to five students formed and used in the classroom only. Others use groups in both classrooms and laboratories. There are also projects that use long term groups (lasting usually at least for one semester) in the class as well in the laboratory. Criteria of group formation vary from project to project or even from teacher to teacher within the same project.

3. THE PURDUE PROJECT

Out of the variety of existing projects, we have chosen one directed by Ed Dubinsky and Keith Schwingendorf at Purdue University. Our selection was based on the fact that this project relies on what we perceive as the proper methodological basis. Most of the Calculus reformers seem to subscribe to the view that the situation in teaching Calculus is so bad that it cannot be made any worse by using computers so that we have nothing to lose in employing the new technology. The Purdue Project, on the other hand, starts from a certain general theory of learning and uses that theory to develop a compatible teaching strategy. Whether the underlying theory of learning is correct or not, is a separate issue and will not be addressed here.

3.1. General Considerations

The Purdue Project relies on the constructivist epistemology based primarily on Piaget's theory of cognitive development (see [18], [19], [20], [21], [22], [23], [24]). The original works of Piaget were recently applied to cover mathematics teaching by Dubinsky, von Glasersfeld, Schwingendorf and others (see [3], [4], [5], [6], [7], [8], [9], [10], [26], [27], [28], [31]). The basic implication of the constructivist theory of mathematics learning is that active construction of concepts is necessary for real understanding of mathematics. The constructed concepts can be then be further reflected on, giving rise to higher-order concepts. In this way, mathematical knowledge spirals onto higher levels of sophistication.

Dubinsky and Schwingendorf ([9], [10], [11], [26]) developed a method of teaching Calculus which, they believe, will help students to acquire a deeper understanding of mathematical concepts through active learning methods in a small-group and computer laboratory environment. Decomposing the basic mathematical concepts, they designed class and laboratory activities in attempt to induce students to go through the developmental steps hypothesized to take place when learning mathematics concepts.

Cooperative learning environment provides an excellent opportunity for the creation of cognitive conflicts which will force students to construct new concepts, or reconstruct and reorganize the existing concepts. When verbalizing their own thoughts, as well as when confronting others' viewpoints, the students are compelled to reflect on their own thoughts, thereby encouraging them to reorganize the material in a new way.

The computers are used in the process of inducing students to make the explicit mental constructions of various mathematical concepts through specially designed computer activities ([9], [10], [11]). Two types of software are used: a symbolic algebra package (most often Maple or Derive) and a mathematical programming language ISETL. Symbolic algebra package is used for learning manipulative skills such as finding derivatives and antiderivatives, simplifying complex expressions, evaluating limits and definite integrals, etc. Using ISETL, which has a simple syntax that is very similar to standard mathematical notation ([14], [15], [27]) and asking the students to write an appropriate computer code induces them to construct something in their minds. It is believed that constructing the code on a computer will contribute to the growth of their mathematical knowledge.

3.2 Purdue Project – Practical Considerations

Since the fall of 1988 several teachers have taught the experimental calculus classes at Purdue University. The experimental sections usually have 25-40 students, with the exception of the fall of 1990 when the sections had about 60-70 students. The sections meet in a classroom three days per week and in a TA directed computer laboratory two days per week. Macintosh computers, ISETL and Maple are used in the laboratory. A textbook written by Dubinsky and Schwingendorf [11] containing sets of classroom and laboratory activities based on the underlying teaching philosophy is used. Small groups are created at the beginning of the semester and they remain unchanged through the course of the semester (and sometimes even through the course of the whole calculus sequence). Groups are created by the teacher in such a way as to be as heterogeneous as possible.[6]

The computer laboratory has 40 Macintosh SE computers and three Laserwriter printers. The laboratory is open most of the day and the evening hours for the use of students from calculus classes as well for other students. The support in the computer lab, for each section of about 30-35 students typically, consists of three undergraduate TA's (working shifts) and one graduate student (monitoring the whole work in the laboratory and not necessarily being in the lab all the time). Generally, TA's are there to help the students with technical difficulties that arise in using the hardware and software and to discuss and pose questions which are to stimulate students' thinking.

The students in the experimental calculus classes are quite similar to those in the regular classes. They are, however, informed before they register for the class that the experimental class load is greater than the regular calculus class.

In the classroom, the students are confronted with problems posed by the teacher which are designed to help them to construct their own mathematical notions which will help them to solve the problems. The students then work in their groups, thinking and discussing the problems for a few minutes. Then the teacher calls the groups (by their chosen names) to obtain responses, asks for comments, and at the end she/he may or may not give her/his own answer. Outside the classroom, the students work in their groups on the laboratory projects and the homework assignments and on the first test.

The laboratory assignments are mostly computer tasks designed for students to investigate and discover the basic ideas about the new calculus concepts. They are usually done before the relevant topics are considered in class. The lab assignments are followed by the classroom discussion which has the purpose of bringing out ideas that the students began to construct. The homework assignments (mostly pencil and paper work) are also done in groups. The goal of the homework assignments is to reinforce the emerging concepts. Each group turns in only one copy of the lab and homework assignments with the signature of all students from the group who participated in completing it. Typically, there are thirteen lab assignments and thirteen homework assignments per semester.

There are three tests during the semester. The first test is a group test conducted in a similar manner as the assignments while the other two tests are individual. The course grade is based on the following: (a) the group grade on the lab assignments, (b) the group grade on the homework assignments, (c) the group grade on the first test, (d) the group grade (average grade) on the second test, (e) the individual grade on the second test, and (f) the individual grade on the final test. In case of the first two exams there is no time limit. The last exam may be common to all calculus sections (experimental and nonexperimental) and there is a time limit.

3.3 Preliminary assessment of the Purdue Project

In general, the evaluation of the effect of instructional treatment is a very difficult task. This is especially true when the effects of two inherently different teaching methods are to be compared. For instance, how do we compare the performance of students who are taught to work in groups and to use computers with that of students who are taught to work alone and not use computers? The second problem is the lack of evaluation instruments designed to test whether the students actually acquired the kind of knowledge that the theory predicts they would acquire. If students are expected to develop concepts, then how are we to check whether they have developed them? It is not at all clear that the typical calculus tests will tell us something about the knowledge of concepts rather than memorization of algorithmic procedures used to solve standard problems.

From the very beginning of the project, it was observed that the test results of students taught using the new methods when answering the questions of a standard test are not worse than those of students taking standard calculus classes. It is only over the last two years that more precise assessments of the effects of the Purdue Project were made. They were primarily devoted to the effects of the collaborative work on learning of mathematics ([30], [31]). It was observed that group work leads to constant creation of cognitive disequilibria which are essential for learning. This is an effect of the multiway communication (when students explain and discuss concepts) that characterizes the group work. It was also observed that students have rather positive (and stable) attitudes towards working in group. The primary reason for this is the fact that groups tend to create support systems for students allowing them to develop self-confidence and overcome frustrations. Another interesting fact is that social roles (leader, manager, spokesperson) emerge in a group leading naturally to team work [31]. On the other hand, these social roles may lead to the division of labor and to students learning only these parts of the material that are part of their role in the group.

It was also reported by some of the teachers using this new method that they were pleased with students' performance and that they have observed that students have learned how to use the computer in conjunction with mathematical theory to solve hard calculus problems.

An extensive assessment of the project is currently under way at Purdue. In addition, as the project spreads to other campuses (for the list of schools currently realizing the project see Appendix 2), a larger volume of knowledge about the effects of this project will be generated.

3.4 Purdue Project outside Purdue University

During the spring of 1991 and 1992, more than fifty mathematics instructors from institutions throughout the United States attended a two and one-half week workshop at Purdue University with the goal of learning how to teach calculus in a new way. Although not all of the instructors who attended the workshops implemented the Purdue Project, the majority of them did. The main reasons for not implementing the project were inability to schedule computer labs for specific coursework, a shortage of faculty, and the perceived inappropriateness of the material for students.

The above mentioned instructors represented a large variety of schools. There were representatives of large four year state institutions, small four year liberal arts colleges, two year colleges and high schools (see Appendix 2). From the reports written at the end of each teaching period it could be noticed that there was no significant difference in implementing the Purdue project at the small colleges and in the high schools from the those implemented at the Universities. The main problems reported with implementing the project (especially from smaller colleges) were related to group work. There are two types of problems. The first one is related to commuting campuses where it may be difficult for students to meet with their groups outside of the classroom. Some instructors solved this problem by meeting their classes in the computer laboratory only. In this way their students had enough time to work in their groups on the homework assignments and the presence of the instructor made it possible to discuss the calculus concepts whenever there was a need. The second type of problem is of a sociological nature and is related to group dynamics. The cooperation in the groups can be hampered by a variety of possible conflicts and requires constant watch from the teacher to prevent it. One of the possible strategies is to meet regularly with the groups (for instance every three weeks) to discuss the problems as they develop. Appendix 3 contains some suggestions for somebody considering implementing a Purdue-type Project; we believe, however, that these comments may be useful for other kinds of calculus projects as well.

4. CONCLUSIONS

Our paper had two goals. The first goal was to present an overview of the current trends in introducing technology to teaching mathematics with emphasis on teaching calculus. The second goal was to give a more detailed description of the project that found a new and interesting way of utilizing computers to teach calculus.

Students entering high schools and colleges expect to be told exactly what mathematics they have to learn and exactly how to solve the problem. The idea of exploring mathematical concepts is foreign to most of them. Changing this situation and converting students from passive into active learners is not an easy task. One of the methods to achieve this goal is to introduce computers as tools to support the teaching process. It should not be, however, a simple introduction of the tool that is not followed by any changes in our teaching style. When introducing new technology we should reflect on the ways that this technology should change our ways of delivering knowledge. We hope that this text will prompt such a reflection.

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APPENDIX 1

SELECTED CALCULUS TEACHING PROJECTS

The material presented here is primary based on [29]. There are many excellent and promising projects which were not considered here, either because they duplicated the content of other projects or because they are not advanced yet.

CLEMSON UNIVERSITY

"Calculator - Based Calculus"

CONTACT: Donald R. L. Torre, Department of Mathematical Sciences, Clemson University, Clemson, SC 29634-1907. e-mail: latorrd@clemson.bitnet

SPAN OF THE CALCULUS COURSES: Single-Variable Calculus (2 terms), Multivariable Calculus (1 term)

USE OF TECHNOLOGY: HP-28S calculators are used as tools for graphing and algebraic manipulations. Students are not required to know programming. The handouts with the programs (if used) are provided.

GENERAL APPROACH: Standard textbooks and the supplementary manuals (collections of calculator enhancement material) are used. Emphasis on teaching basic calculus concepts and their applications (not on technology). Everyday use of calculators enables: (i) focus on graphical aspects, as well as on the essential core of the theory and methods, (ii) motivating students to participate actively in the classroom, (iii) use of advantages of technology.

DUKE UNIVERSITY

"Project CALC: Calculus As a Laboratory Course"

CONTACT: David A. Smith and Lawrence C. Moore, Project CALC, Department of Mathematics, Duke University, Durham, NC 27706. Smith's e-mail: das@math.duke.edu

SPAN OF THE CALCULUS COURSES: Calculus I, II, and III.

USE OF TECHNOLOGY: In the classroom every student must own a scientific calculator. In the computer lab, sixteen students are working on eight IBM computers. Software: EXP (for technical word processing), MathCAD-Student Edition (for numerical and graphical computation and discovery experiments) and Derive (for symbolic and graphical computation).

GENERAL APPROACH: Emphasis on the real-world problem situations, laboratory activities, teamwork, discovery learning, writing and revision of writing, and use of available tools. Lecturing is minimal. Students are working in pairs (teams) on the laboratory activities, submitting a team report once per week; after receiving instructor's comments on that report teams revise and resubmit the report for a grade.

MIAMI UNIVERSITY

"An Alternative Calculus"

CONTACT: Tom Farmer or Fred Gass, Department of Mathematics and Statistics, Miami University, Oxford, OH 450556. e-mail: tfarmer@miavx1.bitnet or fsgass@miamiu.bitnet

SPAN OF THE CALCULUS COURSES: Calculus I, II, and III and one alternative course for the students who have had calculus in high school but not earned AP credit.

USE OF TECHNOLOGY: PC's are used in the classroom and in the lab. Graphical and numerical calculus software locally written is used (recently increased use of DERIVE).

GENERAL APPROACH: Emphasis on group work in class and out, physical demonstrations in class, computers projects and laboratories. The traditional textbooks are used with some rearrangement of the material.

UNIVERSITY OF ILLINOIS

"Calculus and Mathematica"

CONTACT: Don Brown, H. Porta, and J. J. Uhl, University of Illinois, 1409 West Green Street, Urbana, IL 61801. e-mail: horacio@math.uiuc.edu

SPAN OF THE CALCULUS COURSES: Calculus I

USE OF TECHNOLOGY: The laboratory consists of 40 Macintoshes and one NeXT networked together with two Mac's acting as file servers and for submissions of homework. The only software used is Mathematica.

GENERAL APPROACH: Based on the principle that calculation and graphing are the set up for theory which in turn is a set up for more calculation and graphing. The course is taught as laboratory-recitation course with minimal lecturing. Informal groups are used in the laboratory. The core of the course is a dynamic electronic textbook customized by each student.

DARTMOUTH COLLEGE

"Teaching Calculus with True BASIC"

CONTACT: James Baumgartner or Thomas Shemanske, Department of Mathematics, Dartmouth College, Hanover, NH 03755. e-mail: James.Baumgartner@dartmouth.edu or Thomas.Shemanske@dartmouth.edu

SPAN OF THE CALCULUS COURSES: Single-Variable Calculus (2 terms), Multivariable Calculus (1 term), Differential Equations (1 term).

USE OF TECHNOLOGY: Dartmouth College encourages its students to purchase Macintosh machines (about 80% of all students own a Mac). All the dormitories are networked, so that students could use their computers to access the mainframe computers or a public file server which contains course folders for many courses the College offers. True BASIC and Maple are two main languages used for completing the homework assignments and classroom work.

GENERAL APPROACH: Emphasis on the geometrical aspect of a concept and on developing the students' ability to interpret the analytic information geometrically. Standard textbooks are used. No laboratories, major projects or group learning utilized.

THE FIVE COLLEGES

Amherst College, Hampshire College, Mount Holyoke College, Smith College, University of Massachusetts at Amherst

"Calculus in Context"

CONTACT: James Callahan, Mathematics Department, Smith College, Northampton, MA 01063. e-mail: jcallahan@smith or jcallahan%smith.bitnet@cunyvm.cuny.edu

SPAN OF THE CALCULUS COURSES: Calculus I, II, and III.

USE OF TECHNOLOGY: The IBM computers are used in the classroom and in the laboratory. Locally developed software: a variety of graphics programs, and a "template" programs written in Pascal or Basic.

GENERAL APPROACH: Perhaps the most radical reshaping of the calculus curriculum. Goals: (i) for students to learn mathematical concepts from problems from the sciences, (ii) to enhance the student's ability to use calculus in other science and mathematics courses. Taught as a laboratory-lecture course. Computers are used in the classroom, in the laboratory and during the test. Students are encouraged to work in groups in the classroom, in the lab and on homework assignments.

APPENDIX 2

LIST OF COLLEGES PARTICIPATING IN THE PURDUE PROJECT

Faculty	and	Schools
Helen Bahnzof, Seward, NE		Central High School
Charles Bare, Chadron, NE		Chadron State College
Sarah Bates, Decatur, AL		Calhoun Community College
Richard Baynes, Washington, DC		Howard University
Przemyslaw Bogacki, Norfolk, VA		Old Dominion University
Oganes Bogaryan, Bronx, NY		SUNY Maritime College
Agnes Brennan, RSM, Dallas, PA		College of Misericordia
Jo Anne Brooks, Ripley, MS		Blue Mountain College
Bill Covell, Portland, OR		Mt. Hood Community College
John Daly, Oswego, NY		SUNY, Oswego
James Donaldson, Washington, DC		Howard University
Elizabeth Droel, Newport, RI		Naval Academy Prep School
Teresa Edwards, Atlanta, GA		Spelman College
William Fenton, Louisville, KY		Bellarmine College
Monty Fickel, Chadron, NE		Chadron State College
Barbara Frank, Laurinburg, NC		St. Andrews Presbyterian College
Carol Freeman, Lincoln, NE		Nebraska Wesleyan University
Nancy Hagelgans, Wayne, PA		Ursinus College
William Haigh, Aberdeen, SD		Northern State University
Jean Harvey, Collins, MS		Jones County Junior College
Mark Huibregtse, Saratoga Springs, NY		Skidmore College
Paul Hurst, W. Lafayette, IN		Purdue University
Suzanne Joiner, Decatur, AL		Calhoun Community College
Pat Lappenzynski, Dallas, PA		College of Misericordia
Arnold Lebow, New York, NY		Yeshiva University
Paul Levy, Bronx, NY		SUNY Maritime College
William McKinley, Jacksonville, IL		Illinois College
Josiah Mayer, Elmira, NY		Elmira College
Sandy Monteferrante, Oakdale, NY		Dowling College
Jack Narayan, Oswego, NY		SUNY Oswego
Devi Nichols, W. Lafayette, IN		Purdue University
Ken Pothoven, Tampa, FL		University of Southern Florida
Jerry Przybylski, Elmira, NY		Elmira College
Barbara Reynolds, Milwaukee, WI		Cardinal Strich College
Jorge Rivera, Santurce, PR		St. John's School
Keith Schwingendorf, W. Lafayette, IN		Purdue, North Central
Terry Screeton, Rochester, IN		Tippecanoe Valley High School
Shawkey Shamma, Pensacola, FL		University of West Florida
Joel Silverberg, Providence, RI		Roger Williams University
Rick Simon, Omaha, NE		Northwest High School
John Stamper, Sarasota,FL		New College of USF
John Stene, Yakton, SD		Mount Mary College
Alfred Tang, Hayward, CA		San Francisco State University
Hanson Umoh, Dover, DE		Delaware State University
Draga Vidakovic, W. Lafayette, IN		Purdue University
Richard Vogt, Lincoln, NE		Nebraska Wesleyan University
Bob Webber, Farmville, VA		Longwood College
Joe Wimbish, Montgomery, AL		Huntington College

APPENDIX 3

SUGGESTIONS FOR IMPLEMENTORS OF PURDUE-TYPE PROJECT

(1) Find a knowledgeable person to establish the computer laboratory. He or she must have some familiarity with a number of computer systems as well with the software.

(2) Select hardware as early as possible. For running calculus experimental classes with Macintosh: ISETL, and Maple are used. For 386 based PC's, Derive may be used instead of Maple.

(3) The funds are essential. Prepare a complete estimated budget for all costs of establishing the faculty and operations.

(4) Think of people who can help you in the laboratory.

(5) Plan to use the lab as much as possible - make the schedule and priority of the lab usage.