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A Computer Algebra System and a New Approach for Teaching Business Calculus

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In this paper we describe and evaluate a formal experiment that we have conducted at the American College of Thessaloniki. The main aim of the experiment is to evaluate the use of a computer algebra system (CAS) in teaching a Business Calculus course (and compare CAS-based instruction to traditional, non-computerized instruction methods). In particular, we evaluate the efficiency of CAS in realizing the following goals: (a) enhancing the understanding of important mathematical concepts, (b) improving overall performance and (c) making mathematics more interesting and attractive for students. Both subjective impressions and statistical evaluation (based on a large amount of data) are presented. Advantages, possible drawbacks and challenges involved in the use of CAI are discussed.

1. INTRODUCTION

In recent years calculus reform is a hotly and widely debated subject and has motivated a large number of educational experiments (a substantial list of such experiments and related references appears in (Murphy, 1999)). Reform-minded mathematicians have introduced significant innovations regarding the content, the teaching methodology and the general approach to the introductory college calculus course. With respect to content, there is a tendency to emphasize applications and to tone down the rigorous, theorem-proving aspects of calculus (Small and Hosack, 1986; Zorn, 1986; Hodgson, 1987; Brown, Porta and Uhl, 1990). The teaching methodology has expanded to include, in addition to the classical symbolic aspect, the numerical, graphical and verbal aspects of calculus problem solving. Generally speaking the teaching approach of reform oriented courses places emphasis on mathematical exploration (an aspect often overlooked by the classical approach, (Lax, 1984)).

A parallel development of the last decade has been the introduction of computer algebra systems to college education (Murphy, 1999). This has been facilitated by the availability, especially in the last decade, of powerful computer algebra systems on inexpensive personal computers. Systems such as Mathematica, Maple, Derive, Mupad, MathCad etc. are often used for teaching introductory and advanced courses in mathematics, physics and engineering (Smith and Moore, 1990; Hoft and James, 1990; Schwingendorf and Dubinsky, 1990; Ostebee and Zorn, 1990; Brown, Porta and Uhl, 1990).

While the two trends (calculus reform and use of computer algebra systems) are distinct, they are often merged in a single educational experiment. In particular, it has been appreciated that the goal of promoting mathematical exploration (through symbolic, numerical and graphical experimentation) is well served by computer algebra systems (Beckmann, 1988, Ostebee and Zorn, 1990).

In this paper we present a Computer Aided Instruction (CAI) project for teaching Business Calculus, which we have conducted during the academic year 1997-1998 at the American College of Thessaloniki, an international English-speaking Liberal Arts college operating in Greece. The project presented here, lies in the intersection of the two trends discussed above, namely calculus reform and use of computer algebra systems. However, we believe that the combination of several features distinguishes our approach from previous ones. In particular, the following features are worth mentioning.

1. The subject of the course is business calculus (rather than general calculus); this implies a particular emphasis on business applications of the mathematical techniques presented.
2. The computer algebra system we used is MathCad 7.0 Professional; this system is generally not very popular among mathematicians (it is widely used by engineers).
3. We have placed special emphasis on the quantitative assessment of the results of our experiment; we have recorded both student performance in the course and student perception of the course.

The remainder of this paper is organized as follows. In Section 2 we describe the background of our experiment: the educational institution, the problems we needed to address and the ways in which we hoped to remedy these problems through the use of CAI. In Section 3 we discuss issues related to setting up the experiment (objectives of the experiment, software selection, content and structure of the course). In Section 4 we discuss the ways in which the outcome of the experiment was evaluated. In Section 5 we present the final design of the experiment. In Section 6 we present and assess the results of the experiment. Finally, in Section 7 we present our conclusions regarding the particular experiment, plans for possible future extensions as well as some general reflections on the use of computer algebra systems in mathematical education.

2. BACKGROUND AND MOTIVATION

The American College of Thessaloniki (ACT) is an English-language Liberal Arts college situated in Thessaloniki, Greece. The ACT student body is quite diverse, comprising of students from Greece, the Balkan countries (Albania, Yugoslavia, FYROM, Bulgaria), the USA and several other countries. These students have a diverse educational background and different educational goals.

This only exacerbates the usual problems of teaching mathematics to non-mathematics majors. Mathematical preparation and performance are very unequally distributed among our students. Perhaps more importantly, there is a widely varying degree in their acceptance of the relevance of mathematics to their educational and professional goals.

In short, the two main problems we faced in the classroom were *lack of motivation* and *diversity of technical skills* (especially algebraic manipulation skills). We will not expound here the various approaches, which we have used in the past to address the above problems. At some point we decided to explore the possibility of solving the problems (to some degree) by the incorporation of CAI in our classes.

We hoped that CAI would increase the motivation of the students because a computer algebra system offers a much higher potential for mathematical exploration than conventional methods (Heid, 1988; Brown, Porta and Uhl, 1990). For instance, the instructor can follow a more attractive teaching methodology, making greater use of extensive numerical computation and graphical representation. In addition, the instructor may present more realistic examples. More importantly, the student can engage in more extensive and autonomous mathematical activity, without being hampered by possibly inadequate algebraic skills (Small and Hosack, 1986).

This brings us to the issue of technical skills: it is true that the use of a computer algebra system requires the acquisition of computer skills. However, we expected that teaching such skills to our students would present several advantages (as compared to spending more time on teaching *algebraic* skills).

1. Making computer skills a significant component of the course, reduces the overall differential between weak and strong students, because: (a) the initial differential in computer skills is not as sharp as that in algebraic skills and (b) improving one’s computer skills is easier than improving hers/his algebraic skills

2. In particular, one important reason that improving computer skills is easier than improving mathematical skills, is because computers are quite attractive to students and seen as more relevant to their professional development
3. In addition, up *to a certain point*, learning a computer algebra system may be a *mathematically* better investment of time, in the sense that it increases (as explained above) the potential for mathematical exploration.

In 1996, supported by an Andrew-Mellon Foundation grant we embarked on a formal controlled experiment to assess the efficiency of computer algebra based methodology for teaching Business Calculus.

3. SETTING UP THE EXPERIMENT

In preparing our experiment we had to make several choices, regarding the hypotheses to be tested, the technology (especially software) to be used, the structure of the course to be taught, and the method of evaluating the outcome of the experiment.

3.1 THE MAIN OBJECTIVE

Our goal was to evaluate the use of CAI in (a) enhancing the understanding of important mathematical concepts, (b) improving overall performance and (c) making mathematics more interesting and attractive for students.

3.2 TECHNOLOGY ISSUES

Having formulated the hypotheses, which we wanted to test, the next issue to be resolved was the selection of the medium (i.e. software) to implement computer aided instruction. This is a fundamental issue, because the medium in many ways dictates the kind of activities that can be carried out (and hence, to a great extent, the entire philosophy of the course, (Hosack, Lane and Small, 1985; Boyce, 1987; Hughes-Hallet, 1997).

In broad terms, the basic choice was between using (a) a multimedia courseware or (b) a general-purpose computer algebra system (CAS). After a preliminary exploration of the possibilities in each of the two categories, we decided to use a CAS. The main reasons for our choice were the following.

1. The multimedia systems, which we examined, tended to be fairly rigid, leaving little scope for independent exploration by the student. Similarly, such systems were quite restrictive for the instructor, in the sense that designing a new curriculum, best suited to our goals would be a major undertaking as far as multimedia programming is concerned. For example, we were not able at the time to find a business oriented multimedia calculus course. In short, we found that multimedia software promotes ready-made solutions, which is restrictive for both the student and instructor.
2. On the contrary, we found CAS to be relatively easier to program. Hence, CAS could be used in our course in two ways. First, we could use a CAS to design our own notes for the course, having great freedom in material selection and presentation; while at the same time being able to produce fairly sophisticated and aesthetically pleasing material. Second, the same CAS could be used by the students to explore ``hidden aspects'' of the course notes in a guided manner (e.g. guided lab activities) as well as in more autonomous and free form explorations of their own.

Having decided on the use of a CAS, the next step was the choice of a particular software package. The packages we considered were: Mathematica, Maple, Derive, Scientific Notebook, MathCad. Our final choice was MathCad 7.0 Professional, because it combined *all* of the following desirable features.

1. It can handle numerical and symbolic computations as well as create good quality graphs.
2. It has an intuitive interface philosophy, based on a freeform workspace ("worksheet"); mathematical, text and graphic objects can be placed anywhere on the worksheet (compare this with the "command line interface" of other packages).
3. It offers "live" computations, i.e. changing an object on the worksheet results to the immediate update of related objects further down in the same worksheet.
4. Text and mathematics are well integrated in the same worksheet. In addition, text in a worksheet can be hyperlinked to another worksheet; this proved to be a very useful feature in the design of our notes. A built-in browser provides easy access to hypertexts generated in this manner.
5. The students without requiring any programming skills can use the package quite efficiently.
6. Last, but not least, MathCad was relatively inexpensive, both in terms of the price of the software itself, and also in the sense that the software can run on relatively inexpensive hardware (thus it could be installed on the available computer labs).

3.3 STRUCTURE AND CONTENT OF THE COURSE

We must emphasize that the process of software evaluation and selection broadened our perception of the various ways in which mathematical software and CAS in particular can be used in CAI. A specific example will illustrate the point. When we first started looking into available software, our main objective was to obtain a good presentation tool. After having looked at various CAS we realized that some of them could be used for in-class presentation, as well as for dissemination of the course material and for getting the students themselves actively involved in the mathematical process.

It is then obvious that the functionalities of the software determine, to a great extent, the structure of the course. By the time we decided on using MathCad, we had also reached several conclusions regarding the form the Calculus course was to take. The course, which resulted, had the following components.

1. *Course Material*. We used MathCad to write hypertext notes, which were available through the local computer network. In these notes, rigorous derivations were downplayed and more space was devoted to numerical and graphical presentation of limits, derivatives and integrals. Also, we included open-ended questions and a considerable number of Business applications. MathCad was also used to disseminate syllabus information and the course calendar in hypertext form, as well as to assign new homework.
2. *Course Structure*. We opted for spending 25% of the course time in conventional classroom setting and the remaining 75% in the computer lab. Approximately half of the lab time was devoted to computer aided presentations (the remaining half devoted to hands-on practice; more on this in the next paragraph); for illustrating the concept of limit by online numerical computations and animated graphs. A significant part of the classroom time was devoted to active participation of the students; lecturing per se was much reduced as compared to traditional courses.
3. *Course Activities*. As mentioned in the previous paragraph, nearly half the classroom time was devoted to student-centered activities, i.e. practising the use of the software, exploring open ended questions and participating in brief assessment activities.

In order to give an idea of the style of the course notes we present some typical excerpts in Figures 1, 2 and 3.

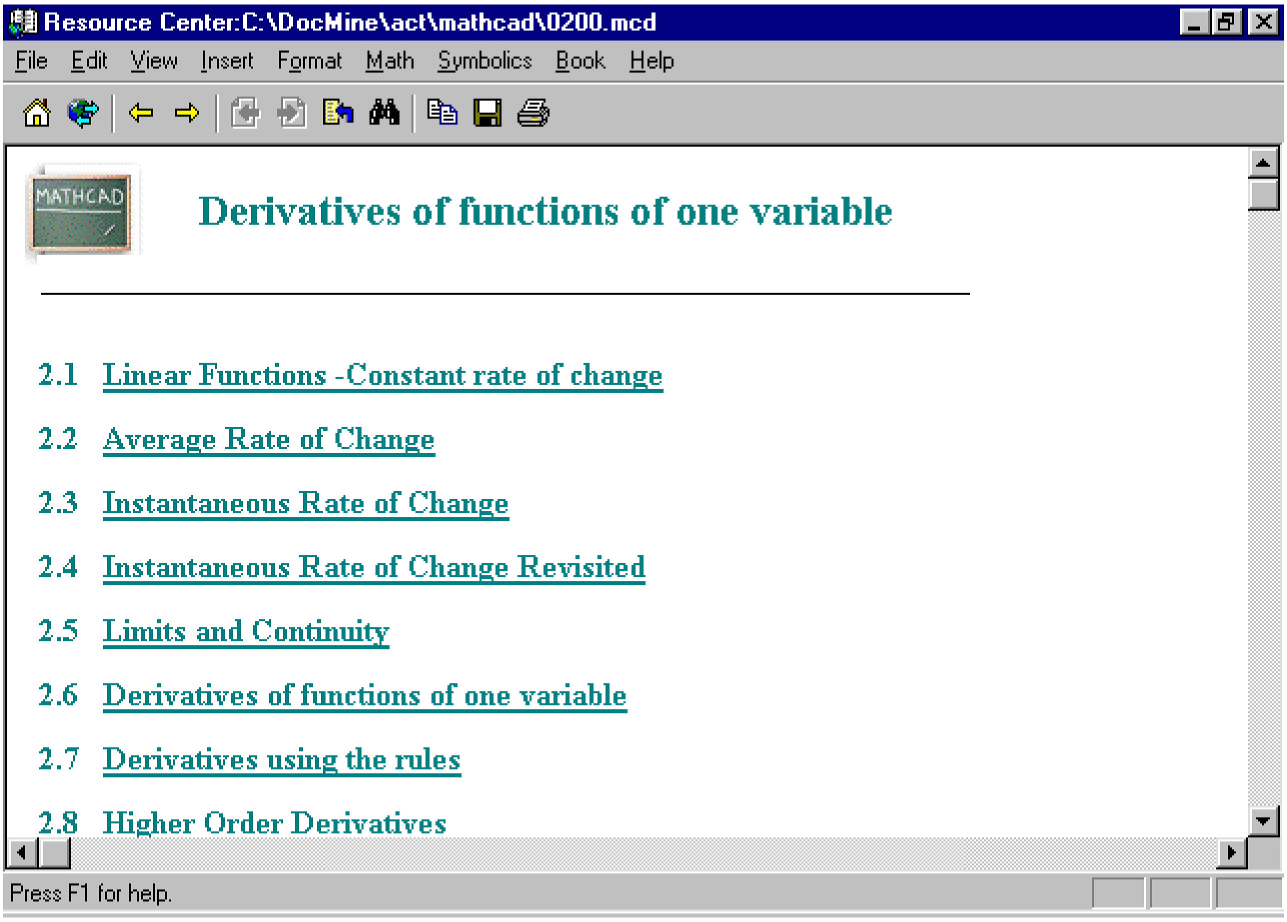

Figure 1.

A hypertext table of contents using the built in browser

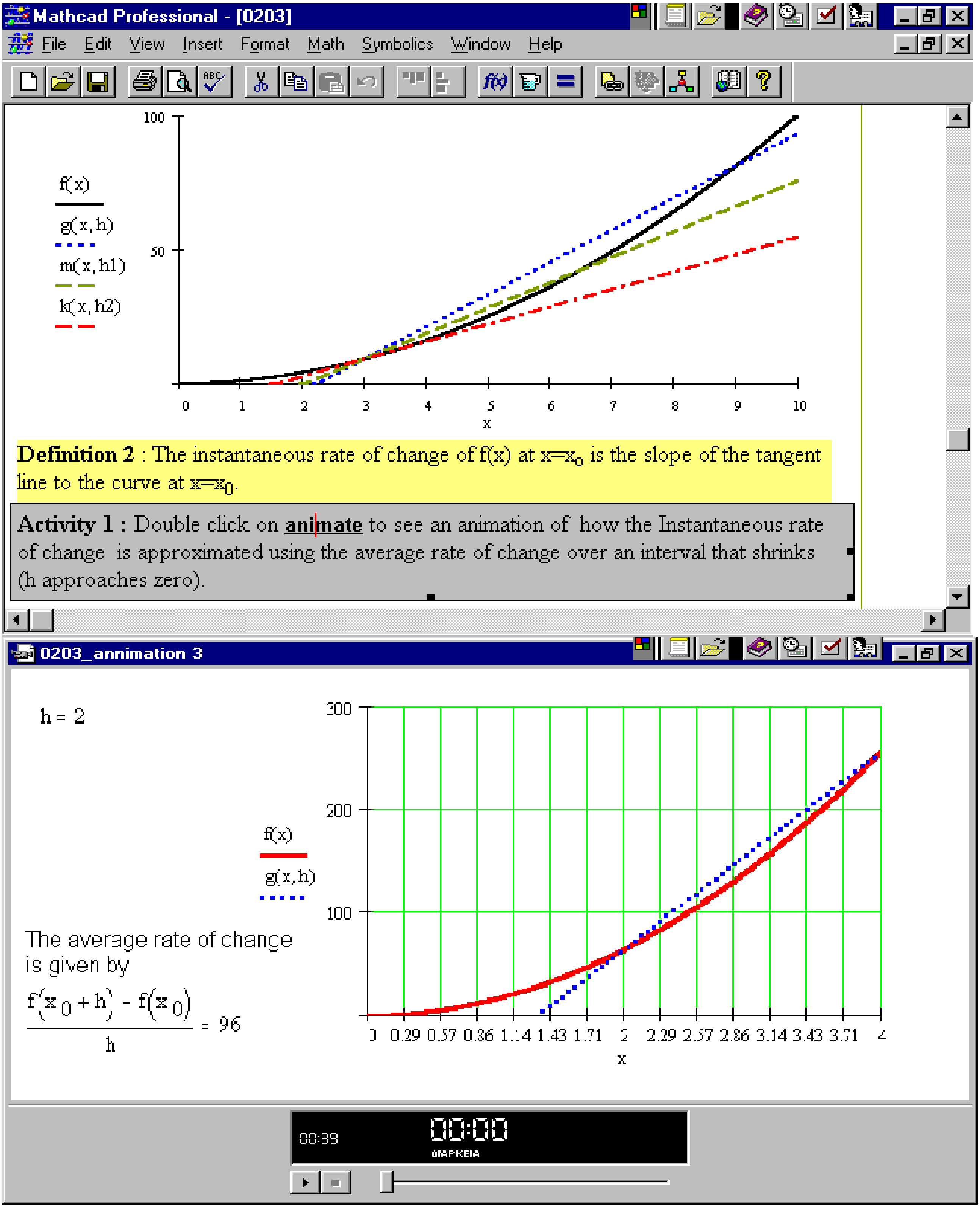

Figure 2:
Activity: A pop up animation

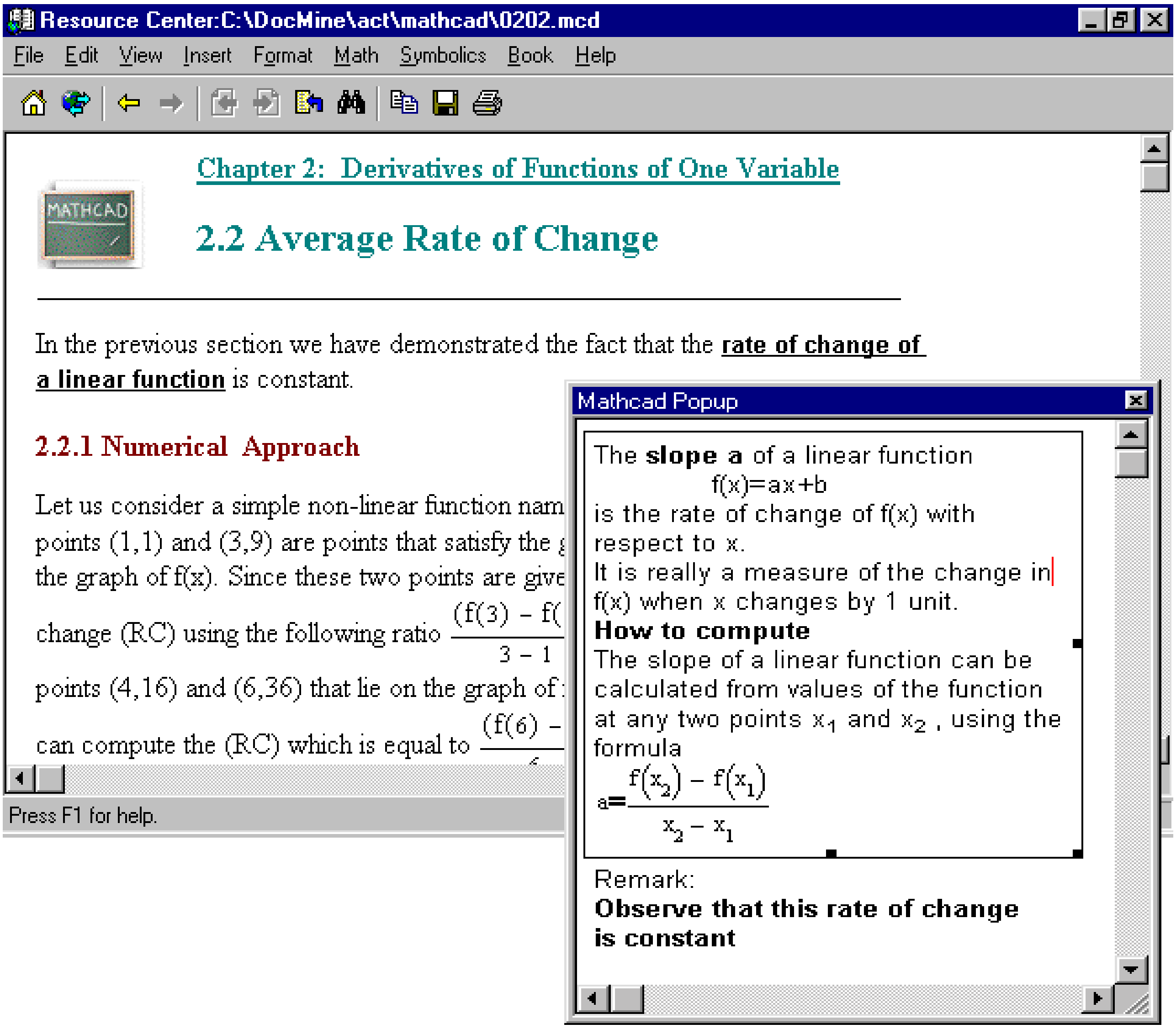

Figure 3

On line pop up help for underlined phrases

3.4 EXPERIMENT DESCRIPTION

The main objective of the experiment was to evaluate the use of CAI along the three dimensions mentioned in Section 3.1. To this end a total of approximately 160 students of the Business Calculus course (Math 101) were involved in the experiment, which took place during the academic year 1997-98. The students formed a total of nine sections. We decided on using two groups: an experimental *test group, which was,* taught the CAS-based course and a *control group, which* was taught a traditional, non-computerized course. Hence, five out of the nine sections formed the test group and the remaining four sections formed the control group. Students in the control group attended a regular class, where there was no computer component, using a paper textbook. Students in the test group attended a lab course (as described in Section 3.3) using the online MathCad notes mentioned above.

To evaluate the use of CAI, we decided to use both subjective impressions as well as formal statistical hypothesis testing. We believe that the two approaches are complementary and each offers information, which is not available through the other approach. Both approaches utilized a large amount of data. In particular, we collected the following data for the participating students.

1. High school GPA and mathematics grades.
2. General college academic performance, as measured by the students' overall GPA.
3. Computer and mathematics aptitude as measured by the students' grades in courses previously taken at ACT.
4. Mathematics aptitude as measured by a pre-test and a post-test (the same test was used for control and test groups). These tests focussed on non-technical aspects of calculus.
5. Questionnaires which were administered at the beginning, middle and end of the semester to measure the students' attitude / perception of the course (Harrison and Rainer, 1992).

6. The formal end-of-semester students' evaluations of the course (such evaluations are routinely collected for all courses at ACT).

4. ASSESSING THE OUTCOME OF THE EXPERIMENT

4.1 SUBJECTIVE ASPECTS

At the conclusion of the experiment our subjective experience indicated that the use of CAI in teaching the Calculus course had both advantages and disadvantages. We are quite convinced that CAI had the following positive effects on the test group students.

1. They were more interested in the subject, spent more time preparing for class and participated more actively in the learning process. This is partly due to the more active character of the CAI course design. But, in addition, we believe it can also be attributed to the appeal of computers as well as to the more advanced and applied nature of the problems discussed (which is again due to the extended possibilities offered by the use of CAS).
2. They presented their work in a more systematic and complete way. We believe this is due to the superior reporting capabilities of MathCad (combining text, mathematics and graphics).
3. They had several different approaches (geometrical, numerical, algebraic) at their disposal for solving a problem; hence when stymied in one particular approach they were able to apply a different one.
4. Students with weak algebra skills were able to 'survive'. We believe this is due to the substitution of algebraic skills with easier to learn computer skills.
5. Strong students had the opportunity to excel. They were challenged in more ways and directions than would have been possible in a traditional class.

6. Both strong and weak students felt more “empowered” than they would feel in a traditional class. This improved their self-perception and, we believe resulted in improved performance; a similar correlation between self-perception and academic performance is established in (Sideridis and Rodafinos, 1998; Rodafinos and Sideridis, 1998).

An additional positive effect of the use of CAI was that the organization of the course improved: a complete set of electronic notes was prepared and was available from the beginning; problems and exercises were available on line; all important information about the course was on line (syllabus, important dates, graded quizzes and assignments). A better organized course resulted in better organized students as well.

Our experiences were not entirely positive. We also perceived possible traps in the use of CAI, which we tried (we hope effectively) to avoid. We believe instructors who plan to use CAI in their classes should be particularly careful about the following points.

1. Having to teach the necessary computer skills may create an ‘overhead’ and reduce the time available to cover actual mathematical material. However, it must be pointed out that, if the overhead is kept under control, *more* mathematics can actually be introduced in less time (increased “productivity”).
2. The learning process may degenerate into an exercise of computer gaming, if particular emphasis is not placed in planning the classroom activities and teaching strategies (Wu, 1997).
3. The students may face difficulties in subsequent courses because they will become too dependent on the computer, especially for performing symbolic manipulations. This can be characterized as the “incompatibility” effect, which may be a serious problem until the time when CAS is integrated in the curriculum.
4. The radical shift in the learning paradigm may cause disorientation (*to both instructor and students!*).

4.2 STATISTICAL EVALUATION

In this section we present a *statistical* evaluation of the CAS benefits. As mentioned in Section 3.1, we are interested in evaluating differences between the test and control sections in the following areas:

1. Enhancing the understanding of important mathematical concepts.
2. Improving mathematical performance.
3. Making mathematics more interesting and attractive to the students.

In addition to the above, we are interested in finding possible differences in the background of the students who participated in the CAI and traditional sections. Specifically, for each of the twelve variables listed below, we test (using the t-distribution hypothesis test) the null hypothesis: that the respective variable has the same distribution for the student sample coming from the CAI and the traditional sections. We list below the names of the variables considered their numerical range and present a few explanatory remarks for each variable. In the perceptions / attitude questionnaires higher values in the scale from 1 to 5 indicate more positive attitude.

1. **M100 Grade (0 to 4).** The grade received in the introductory math course (a prerequisite to Math 101, the business Calculus course). It is assumed that this grade is correlated to mathematical proficiency of the students at the beginning of the experiment.
2. **CS101 Grade (0 to 4).** The grade received in the introductory computer science course. It is assumed to reflect computer proficiency of the students at the beginning of the experiment.
3. **M101 Grade (0 to 4).** The final grade received in the business Calculus (Math101) course. It is assumed to reflect mathematical proficiency (regarding both technical skills and conceptual understanding) at the end of the experiment.
4. **M101–M100 Grade.** This is the difference between items 1 and 3; it reflects the *differential* in mathematical proficiency which resulted from taking the (CAI or traditional) Calculus course.

5. **GPA.** This reflects the overall academic performance of the students.
6. **Preliminary Concepts exam (0 to 4).** This quantity is the grade received in the *mathematical concepts understanding* pre-test, administered at the beginning of the course.
7. **Final Concepts exam (0 to 4)**. The grade received in the *mathematical concepts understanding* post-test, administered at the end of the course.
8. **Prelim. Concepts – Final Concepts.** This is the difference between items 6 and 7. It reflects the *differential improvement* in understanding mathematical concepts (presumably resulting from taking the course).
9. **CS attitude (1 to 5).** This variable was obtained from a perception / attitude questionnaire (see Appendix) administered to the students at the end of the course. It is actually the average of the eleven computer related questions of the questionnaire.
10. **Math attitude (1 to 5).** Similar to the previous variable, it is the average of the fourteen mathematics-related questions of the questionnaire.
11. **Q: I look forward to coming to class (1 to 5).** This and the next variable are obtained from questions 1 and 5 at the final part of the questionnaire. They are used to obtain an estimate of the students' attitude to the course (rather than to mathematics in general).
12. **Q: I will recommend this class to a fellow student (1 to 5).** See the previous item.

In Table 1 we present the results of the hypotheses tests. In each row of the table we list the average value of the variable for the test and control groups, the corresponding t-value and the corresponding p-value, i.e. the probability that the CAI and traditional samples come from the same distribution. Underlined variables show a statistically significant difference (at the 10% or better significance level).

No.	Variable	CAI average	TRA average	t-value	p-value
1	M100 Grade (0 to 4)	2.68	2.52	0.818573	0.414588
2	CS101 Grade (0 to 4)	3.00	2.83	1.125226	0.262649
3	<u>M101 Grade (0 to 4)</u>	<u>2.47</u>	<u>1.94</u>	<u>2.469418</u>	<u>0.014894</u>
4	<u>M101–M100 Grade</u>	<u>–0.21</u>	<u>–0.59</u>	<u>2.166143</u>	<u>0.032213</u>
5	<u>GPA</u>	<u>2.86</u>	<u>2.51</u>	<u>2.525280</u>	<u>0.012811</u>
6	Preliminary Concepts exam (0 to 4)	1.41	1.17	1.639328	0.103659
7	<u>Final Concepts exam (0 to 4)</u>	<u>3.06</u>	<u>2.58</u>	<u>3.073958</u>	<u>0.002594</u>
8	Prelim. Concepts – Final Concepts	1.65	1.40	1.356195	0.177482
9	CS attitude (1 to 5)	4.2	3.93	2.114560	0.366093
10	<u>Math attitude (1 to 5)</u>	<u>4.02</u>	<u>3.84</u>	<u>1.827858</u>	<u>0.070141</u>
11	<u>Q: I look forward to coming to class (1 to 5)</u>	<u>3.80</u>	<u>3.396</u>	<u>2.319737</u>	<u>0.022104</u>
12	Q: I will recommend this class to a fellow student (1 to 5)	4.03	3.74	1.635201	0.104718

Table 1

We should emphasize that we take the above statistical analysis as just one element in our general evaluation of our experiment. In particular, we do *not conclude* that differences in some of the above variables positively prove that CAI students did better than traditional students. However, the statistical analysis does offer some indications and some *tentative* remarks can be made regarding Table 1. (A more complete discussion appears in Section 5).

Attitude. Regarding the students' *attitude to the course* (items 11 and 12), it appears that CAI students exhibit a markedly better attitude than traditional ones. This is more obvious in item 11, with a p-value of 0.022104 (i.e. statistically highly significant); in the second question CAI students again have a more positive attitude which is nearly significant at the 10% significance level (p-value is 0.104718). As far as *general mathematics and computers attitude* goes, it is clear that CAI students have a more positive attitude towards mathematics (item 10, p-value is 0.070141). We find quite interesting the fact that there is no significant difference of attitude towards computers (item 9, p-value is 0.366093); it appears reasonable that students with a better attitude to computers would be attracted to a CAI math course. The reader is reminded that results presented here pertain to attitudes at the *end of the course*; it is interesting to also compare computer attitude at the *beginning of the course,* as well as to compute *differential attitude* from the start to the end of the course. It is possible that CAI students "overdosed" in computer technology.

Mathematics and computers preparation. The CAI group has higher grades in introductory courses in both mathematics and computers; it is plausible to assume that they are also better prepared in these subjects. However, this difference is *not* statistically significant (items 1 and 2, p-values 0.414588 and 0.262649, respectively).

Mathematical proficiency. Math101 grade difference is statistically highly significant (item 3, p-value is 0.014894) and the differential between Math101 and Math100 grade is also statistically highly significant (item 4, p-value is 0.032213).

Conceptual understanding. There is a statistically significant difference between the CAI and traditional groups in their performance at the Preliminary Concepts exam (item 6, p-value is 0.079916), as well as at the Final Concepts exam (item 7, p-value is 0.002594). The differential performance (i.e. difference in performance at the end and beginning of the course) is *not* statistically significant (item 8, p-value is 0.177482).

5. CONCLUSIONS

The new approach in teaching Business Calculus through the introduction of a computer algebra system is overall positive. Students in the test group, outperformed students in the control group. They did better not only on the post-test, where the emphasis was placed in concepts, but also on their final course grades. Furthermore, they had a more positive attitude towards the course, considering it more challenging and interesting and as a consequence they have spent more time on the course. The introduction of more sophisticated applications and more open–ended questions, that allowed room for exploration, did not only please the students but also the instructors involved.

Computer Algebra systems have definitely a place in Mathematics instruction, but they have to be introduced cautiously. The introduction of the technological medium will not on its own produce a better course. Substantial work is needed to modify the content the structure and the teaching strategies of the course so as to adjust it to the new teaching approach. New problem sets have to be written, solutions to old problems have to be reworked and a larger emphasis must be placed on exploration. The time needed for students to develop the computer skills needed to fully exploit the capabilities of the CAS creates an overhead that is not to be ignored and the instructor should try to keep a fine balance between the technical and the mathematical component of the course.

Finally the introduction of CAS in Mathematics courses should not be considered independent of the overall curriculum. Such an introduction must be fully integrated into the program of study so as to avoid cases where the new skills developed are left unappreciated.

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BIOGRAPHICAL NOTES

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