A summary about the experiences how to integrate personal computers and hand computers (TI-89/92) in Mathematical Education in Austria.

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1. INTRODUCTION

The use of computers in mathematical education in schools depends on some very important conditions. The use of the computer has to be required in the **curriculum**, sufficient **hardware** and good **software** has to be bought and the computer is to be admitted in **oral and written exams**, inclusive the final examinations. All these conditions have been fulfilled to a great extent for grammar schools, business academies, secondary technical and trade schools in Austria in the last ten years. Therefore it depends primarily on the mathematics teacher, in which way and how intensively the computer is used in mathematical education.

Up to 1990 the minimum equipment in grammar schools, business academies, secondary technical and trade schools in Austria was **two computer labs**, one of which always met the requirement of even large classes, where very often two students were working per computer. But they suffered from a lack of really useful software. At that stage teachers used computers only together with other media like overhead projectors, film projectors, television etc.. Some teachers in Mathematics motivated students to solve mathematical problems with the help of computers in optional afternoon classes or at home. In the mathematics lessons these students explained the methods for solving the problems which they had worked out with the computer to their classmates [24].

2. FIRST COMPUTER ALGEBRA SYSTEM

In spring **1991 DERIVE 2.x** was bought with a **general licence for all Austrian schools** preparing students for university level. This led to the foundation of two organisations for mathematics teachers, the AMMU and the ACDCA.

In the winter of **1991** the **AMMU** (**A**rbeitsgruppe für **M**odernen **M**athematik-**U**nterricht) began to exist. The goal of the working group was to consider, how and to which extent the computer should be integrated in mathematical education and in addition how it could help mathematics teachers to get new ideas and useful materials. Two publications per year were issued and meetings for teachers in mathematics, especially for **business academies and secondary technical and trade schools**, were organised. These schools are attended by approx. 44% of all students prepared for university studies. In the homepage ***http://www.ammu.at*** the latest publications are published and the date of the next meetings are announced.

In the spring of **1992 ACDCA** (**A**ustrian **C**entre for **D**idactics of **C**omputer **A**lgebra) was founded. It was founded in order to create a forum for ongoing discussions and research concerning the use of CAS in teaching mathematics, especially in **arts grammar and science grammar schools**. Grammar schools are also attended by approx. 44% of all students prepared for university studies. Conferences, meetings and publications are intended to offer a framework for university teachers, teacher trainers and school teachers to exchange their experiences and to do research projects (Homepage: ***http://www.acdca.ac.at***).

3. DERIVE-PROJECT

In 1993/94 the **Austrian CAS I Project (DERIVE)** involving 700 students, 17 schools and 28 mathematics teachers was carried out. The leading principle for the research teachers was the **white-box/black-box principle** of B. Buchberger (Research Institute for Symbolic Computation of the university of Linz) [6]:

The teaching of an area of mathematics proceeds, roughly, in two phases:

The white box phase: This is the phase in which the area is new to the student. In this phase, the use of math software systems for solving the problems of the area under study is (at most times) inappropriate. Students should study the area thoroughly, i.e. they should study problems, concepts, theorems, proofs, algorithms, examples, and hand calculations.

The black box phase: After the area has been thoroughly studied, algorithms developed in this study can be called as black boxes in the later study of hierarchically higher areas.

One topic where the white-box/black-box principle can be used in a wonderful way is Algebra. First the students learn to transform terms, afterwards to solve a linear equation stepwise with or without DERIVE. When they have done well they are allowed to take the command *SOLVE* to get the solution at once. When they have to solve a system of linear equations for the first time they first have to reduce the system to one linear equation with one variable. They are already allowed to solve this equation with *SOLVE*. Once they can do such reductions in a reasonable time, they are allowed to use the command *SOLVE* for a system of equations too [16].

B. Buchberger also admits that there are exceptions to the white-box/black-box-principle. "It may sometimes be reasonable to play, first, with an algorithm as a black box in order to obtain a better understanding of the problem before one goes into the details of teaching the underlying theory. This may well be reasonable in certain situations." (**Black-box/white-box-principle**)

This modification was first suggested at a Spring School on Didactics of Computer Algebra in Krems (Austria) 1992. It was exemplified in the lecture "Introducing Calculus with DERIVE" [20].

The mathematics teachers in the DERIVE-Project were supported through the research of K. Aspetsberger, who reported about his own experiments with CAS for the first time in 1989 [2]. He created the **module principle**. He discovered that the intensive use of functions in mathematics lessons using computer algebra systems led the students to a new understanding of functions. In contrast to regular mathematics lessons where students see functions like objects having certain characteristics, functions in computer algebra systems are seen as tools for computing certain tasks. In the project several sorts of modules could be distinguished.

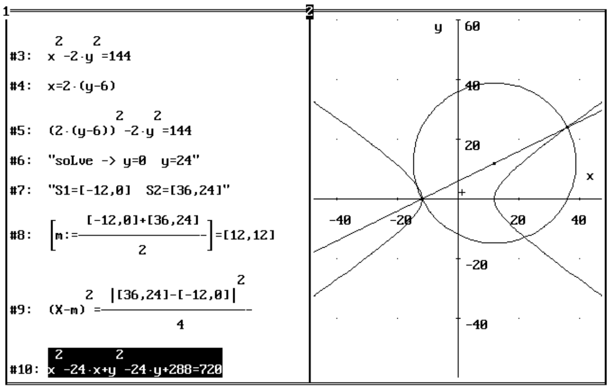
DERIVE-modules used as black boxes or sometimes made "white" when teachers are using the black-box/white-box-principle e.g. CROSS(a, b) to get the cross product of two vectors or modules like ODE1 to solve differential equations.

Modules created by the students in the white box phase. The main goal is the cognitive learning process during the production of the module.

Modules created by the teacher and used by the students as black boxes (utility files).

K. Aspetsberger reports that good students can sometimes create their own system by defining new functions with the experience of programming.. But he also admits that less able students often make use of modules without a detailed understanding of the problem and use functions without reflecting upon whether the functions are appropriate for solving the particular problem. Students and teachers have more difficulties to detect errors if students do not know the way the functions work [4].

Beside the classical use of computer algebra systems for symbolic differentiation and integration **DERIVE can also be used for analytic geometry**, which is a very important part in the mathematics curriculum in Austria. Here one can use DERIVE for doing the symbolic calculation e.g. solving equations as well as for demonstrations of geometrical objects in 2D-windows. Functions for manipulating vectors can be defined by the user [3]. It is preferable to split the screen into two windows. The first one is normally for the algebraic manipulations, the second is the 2D-plot window for visualising the geometric objects.



With these two windows it is now possible to work simultaneously. By repeatedly shifting between the windows the ideas or results of one window can be used in the other one. This multiple window technique is named **window-shuttle principle** in Austria. It is a technique which many students like to use to get new ideas or to control their calculations.

4. The INFLUENCE of CAS in LEARNING MATHEMATICS

One possible model to describe "*how we do mathematics*" is the **spiral of creativity** by B. Buchberger [7]:

Experimental Facts
Computational Results

COMPUTING INVENTING

Algorithm Conjecture

PROGRAMMING PROVING

Theorem

The spiral begins with the observation of data materials or with a problem, the solution of which can be found in the development of algorithms or in the creation of new concepts.

Through analysing, experimenting or generally through heuristic strategies conjectures are found, theorems are formulated and ideas of proof sought.

If you are content with the result after entering the circle once or repeatedly, you can **go up to a higher level** of the spiral. You are in the next level because you have found a better knowledge or a better algorithm.

B. Buchberger notes that his answer is "*recursive*" and can govern maths education at all levels and areas of mathematics including the elementary first steps in mathematics at high school as well as the most advanced areas in university mathematics [6].

H. Heugl, the chairman of ACDCA and organizer of the DERIVE-Project, recognizes **three stages in learning mathematics** if students are using symbolic computation systems in the classroom [14]:

Stage I – the heuristic stage
Typical activities: finding conjectures, trying to devise problem solving strategies, student oriented experimental ways of learning, methods of trial and error, testing models, testing and interpreting results.

Stage II – the exact stage
Typical activities: corroborating assumptions, deducing algorithms, proving theories.

Stage III – the application stage
Typical activities: applying algorithms, solving problems, modelling, looking for more suitable models for real life problems, using the CAS as a black box for operations which students developed themselves in stages I and II and then testing and interpreting.

H. Heugl notices that in traditional mathematics education the experimental or heuristic phase often does not exist. In the Austrian DERIVE-Project, however, the growing importance of the student oriented experimental phase in learning mathematics is an important result.

5. A COMPARISON of LESSONS with and without the USE of COMPUTERS

In 1994 a classroom observation of 20 lessons with and 37 lessons without the use of computers took place. The observation was made in Austrian grammar schools with 15 to 17 year-old students. A special pattern was used to cover important aspects of classroom methodology in teaching mathematics. Some results are showing significant differences in the activities of students and teachers when using a computer [18].

A significant difference is the way students work: The use of computer packages results in **more independent productive student activity**. Individual student activity nearly erased student calculating on the blackboard. Computer lessons imply less class teaching and more partner and individual work as well as less note taking and more production. On the other hand a lot of time is devoted to the students to enable them to work with the computer and the program.

Some interesting facts result from an analysis of the correlations between some parameters which influence the situation of the teacher. The **stress of the teacher** during computer periods **depends** mainly **on the number of students**. During standard lessons this parameter is not so crucial, but the working climate is decisive. **Working climate** has been generally found to be **better in computer classes**.

The common technical equipments in special computer labs result in laboratory effects, the use of notebooks is one way towards integrated use of computer algebra packages.

6. ASSESSMENT

When CAS is used, the classroom interaction between students and teacher changes. Students are eager to exert more control over their own activities, thus lessening teacher control of the classroom. With the richer computational environment provided by CAS, students take a variety of paths in investigating a problem and arrive at different representations of the answer. The situation is also likely to result in **a new role for the teacher**. As teachers become partners rather than leaders in the classroom, mathematics become **more student-oriented and less teacher centred**. Groups of students can work together as a team and the answers given by the computer will often be discussed within the groups of students and sometimes between students and the teacher. Bright students, who have solved their mathematical problem, can assist those who are slower. They can get additional marks for their contributions towards helping slower students [25].

When groups work on CAS activities in class, some of the teacher's time is released for use in **informative assessment**. The teacher spends less time at the board, and can circulate within the classroom in order to discuss progress with the students, note particular success or failure, give guidance and support. In this way a considerable proportion of assessment credit may reasonably be given to coursework.

7. TESTS in MATHEMATICS with the Use of a PC

In Austria **50% of the credit** should be awarded **for work carried out in the classroom** and marked by the teacher. In traditional mathematics education, however, the marks in the mathematics tests are decisive for the mark in the certificate. Thus it happens that coursework often represents only 20% of the credit in reality, because traditional teachers have too little information about their students on a day-to-day basis.

In Austria, teachers of Mathematics at schools which are preparing students for university can choose and formulate their own test problems. Since 1985 they have been in a position to allow students to use electronic calculators in tests, if they have enough practice in class with it. From 1991 onward computer algebra systems like DERIVE or MATHEMATICA have been used. In doing that **three models of assessment for tests** have developed. But it is not easy for the teachers, because in big classes there are often more students than computers available, not every student has a computer at home and not all lessons can be held in a computer lab. Therefore three practicable models for tests have developed.

Model I with **different examples for students with/without CAS** is a favourable interim model for classes, where a strong minority is against using CAS in mathematics tests. It is a fact that the handling of the computer and the finding of appropriate DERIVE-commands leads to a remarkable difference after some weeks between those students who have the chance to practise at home and those who do not have this opportunity [23].

Model II with **time-sharing on the same computer** between two students is only sensible if 50% of the test and time can be worked on without a PC and 50% with a PC. This model was partly used in the Austrian CAS-I-Project (DERIVE). The two students sharing the time of working on the computer, got different examples. Changing turned out to be no problem [15].

Model III with **50% team work** alternating with **50% single work** on the same computer, is part of the concept MATHS & FUN with MATHEMATICA. For studying the concept see http://www.mathsnfun.ac.at. It is an educational experiment at the Business Academy I in Graz. Two out of three mathematics lessons per week are in the computer lab, where the students have to work in teams of two and this is the reason why they write their **tests in teamwork,** too. Most students involved have reacted very positively on those team tests within the framework of educational experiment. However, there has also been some very negative feedback, but also some suggestions of improvement on the part of the students [22].

But **the real goal in mathematical education is one student per computer** in lessons and when writing tests.

8. TI-92-PROJECT

In the German report of the Austrian DERIVE-Project H. HEUGL writes**:** *„It would be ideal if every student had a portable CAS-calculator, which could be linked up with the CAS in a computer lab, in his school bag.“* [15]

In Autumn 1996 the TI-92 came on the market and the planning of an **Austrian CAS II Project (TI-92-Project)** involving 1500 students, 46 schools and 70 mathematics teachers began. It was carried out in 1997/98. Half of the research teachers came from the CAS I Project, half of them were new.

All teachers had to be trained handling the TI-92. It was great luck that just at the right moment the world wide T³-Project "**Teachers Training with technology**" started in Austria. The didactical ideas with the TI-92 in the start phase were written down in the book "Der TI-92 im Mathematikunterricht." [5]

The project was designed with the experience gained with the design of the CAS I Project. It is useful for investigations concerning the use of computer algebra systems in mathematics to concentrate on a few topics only. Those topics in the CAS I Projects are called **observation windows** [8]. In every form two observation windows were taken. In the 9th form, where thirty teachers were engaged, the first observation window e.g. was to find out the various methods the students were taking with the TI-92, when they had **to solve a quadratic equation for the first time**. They had to do this in at least three different ways within a time limit of twenty minutes [26]. It was surprising which variants of right ways the students found.

Different ways	*SOLVE*	*Graph*	*Table*	*per hand*	*FAC-TOR*
percent	93%	50%	39%	4%	3%
number of ways	*0 way*	*1 way*	*2 ways*	*3 ways*	*> 3 ways*
Percent	7%	35%	18%	30%	10%

The statistics show that the method with the graphic window (Intersection and Zero) and with the table window was very often taken. Both variants of solution strongly influenced the further mathematical education in the research classes.

Beside the observation windows the other goals of the project were to study: the basic principles of teaching mathematics with the TI-92, the basic skills which students have to learn with it in mathematics and the influence of the TI-92 on oral & written exams.

9. COMPARISON of the Use of DERIVE and the USE of TI-92

In addition to the observations made by the research teachers, an independent centre of school development (**Z**entrum für **S**chul-**E**ntwicklung), which is an institute of the ministry of education, questioned the teachers and students. The results were published in three reports [9],[19],[10]. The ZSE-Reports contain some interesting and sometimes surprising results:

With the use of the **TI-92 fun in mathematics lessons increases at every level**, with DERIVE this effect only turns up from grade 9 (15 years old students) onwards.

The **largest increase** of fun with DERIVE was noticed in grade 9, with the TI-92 in grade 7 and grade 11 respectively.

In both, the PC-DERIVE and the TI-92 project, **boys derived more fun** from it than girls.

Whereas in the TI-92 project the **TI-92** was **a great help** for more than two thirds of the students **in at least three fields** (tests, home assignment and problem solving in school), only about half of the students in the DERIVE project thought **DERIVE** helped them and that only for the problem solving at school. So the **advantage of the TI-92 is its availability at all times.**.

10. TESTS in MATHEMATICS with the Use of the TI-92

In the **Austrian CAS II Project (TI92-Project)** the students of the seventy research teachers wrote their tests in mathematics with the TI-92. At their final meeting in 1998 the teachers collected their most important and sometimes unexpected results [17]:

The problems in tests have to be formulated **more goal oriented,** that means the **texts are longer** instead of shorter.
For solving problems it is very important **not always to insist on the use of the TI-92**.
Students find **new ways with the TI-92,** this means more work for the teacher.
The TI-92 has no floppy. The students have to make **much documentation** in the test book, therefore **fewer examples** are set.
There are two difficult decisions: What is to be the **minimum knowledge** in mathematics **without** the TI-92 ? What **minimum knowledge of TI-92-commands** is an absolute must ?
Modules and **programmes** are a good chance **for good students,** but **a new problem for bad students**.

After the TI-92 project was finished nearly all research teachers wished a further project because many problems had arisen and were to be solved. In addition it was clear that the next project had to be an open project not one fixed on the TI-92 only.

11. The PROJECT about ELECTRONIC MEDIA in TEACHING MATHEMATICS

After a meeting of the project management five topics were chosen for the CAS III Project. 2000 students in 70 experimental classes from grade 7 to 11 took part in this project. It was carried out in 1999/2000. The general report (in German) has just been finished. See home-page of ACDCA http://www.acdca.ac.at/.

Topic 1: Electronic Teaching and Learning Materials
It was the goal of a team of research teachers to collect, to adapt and to disseminate teaching and learning materials. One means of achieving this was the **production of the ACDCA homepage** as a forum for discussion and information for teachers and students. The first publication on the homepage was the final report of the CAS II project together with all the materials developed. Then all new information for the research teachers of the CAS III project and at last the final report was published on the new homepage **http://www.acdca.ac.at** [21].
In addition **a CD-Rom with the general report of the CAS II project** was produced by the group in 1999 and then sent to all the research teachers [1]. The CD-Rom also contained important software e.g. the latest Acrobat-Reader and Netscape for installation, a list of important internet links and some useful utility files.
Later on there were **T³-meetings** in every county of Austria **to teach how to use the internet for mathematical education.** For these meetings a further CD-Rom was produced for all participants. The CD-Rom contained the basic knowledge for using the internet, some evaluation materials, links and programs (applets), files and programs from Texas Instruments and an offer of important software [11]. The goal of these meetings was to provide the mathematics teachers with the right software so as to be able to use the internet as a learning medium and a source of materials.

Topic 2: TIMSS and CAS supported teaching of Mathematics:
Based on the results of TIMSS (Third International Mathematics and Science Study) experts examined as to which extent the use of electronic media can contribute to improve the quality of teaching mathematics. First a group of experts discussed the questions "*What is a good education in mathematics?*" and "*Who is a good mathematics teacher*?", and based on their discussion they formulated a thesis paper to produce **tests for the evaluation of the goals of mathematics education** in CAS supported and not supported classes. The tests, which had to be easy to evaluate contained a mixed bag of examples/problems: very short ones which could be solved in the head (a calculator was not necessary, but not forbidden), questions concerning the actual class work of the corresponding age group and problems independent of the actual class work and to be remembered for a lifetime.

1277 students from 74 classes (grade 9 to 11) were tested at 26 schools all over Austria. In 39 classes students had a CAS-hand-calculator (TI-92 or TI-89) and in 35 classes they had a traditional calculator (TI-30 or similar). The testing was carried out at the end of the school year 1999/2000. The results showed that the **CAS-classes were better in all the three grades tested**. There were differences which were slight, but significant. For tests, dates and exact results see the ACDCA-homepage [12].

Topic 3: The Production of a commentary.
In addition to the mathematics curriculum (grade 9 to 12) **for CAS-supported education** a commentary covering all important themes of the curriculum such as vectors, trigonometry, calculus, system dynamics, statistics and probability theory was published on the homepage to enable every teacher interested in a specific topic to download it.

Topic 4: The new Learning Environment with CAS.
As CAS supports new teaching and learning strategies, the aim of this part of the project was to develop and test materials which support the new teaching and learning

strategies such as open learning activities based on actual research. In teamwork useful materials were produced for many themes of mathematical education which can be downloaded from the ACDCA homepage by every teacher who wants to try them in his class work.

Topic 5: The influence of CAS on the Examination Practice. A short time after the CAS II project a team of teachers under the leadership of H. Heugl developed **some variants of a new model of assessment**. In accordance with the Ministry of Education experimental studies to test the new model were carried out in 1999/2000. One fundamental idea of all the variants was to use the pre-set time for written tests in a school year – e.g. 350 minutes in form 11 - in different ways [27]:

For short tests - up to a maximum of 25 minutes - to check reproductive skills or reproductive knowledge with or without CAS.

For one longer test per half-term, e.g. 100 minutes, to check problem solving skills. There should be sufficient time to experiment, and to use materials which have been worked out at school or at home.

For working out a short chapter of mathematics, which has not been dealt with at school. Each student should prepare his short chapter in written form at home and present it to his classmates at school.

The problems of the Examination Practice in CAS supported classes are of such great importance that they led to an international ACDCA-Conference which took place in Portoroz, Slovenia, in July 2000. Its theme was "*Exam Questions & Basic Skills in Technology-Supported Mathematics Teaching*". In the centre of the conference was the question "What are **the indispensable Manual Calculation Skills** in a CAS-Environment?" [13]. The lecture was published and initiated an intensive discussion in Europe and every mathematics teacher using CAS in his mathematical education is continuously faced with it.

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