The use of symbolic algebra in learning mathematics: the barrier from formal examination schemes

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Using technology in the teaching and learning of mathematics requires, among other things, positive attitudes from students and teachers. In this study, two teachers helped design and then taught two courses of mathematics to four groups of upper secondary school students. Two of the student groups had full access to graphic calculators with symbolic algebra systems and the other two groups had full access to graphing calculators without symbolic algebra software. In this paper we report on the student attitudes and beliefs about using technology in their course within a curriculum that restricts its use in a 'final matriculation examination'. The outcomes suggest that integrated technology teaching impacts in a complex fashion on student attitude. The results of this study suggest that the nature of the assessment system which forms part of the curriculum influences the attitude towards rich usage of the technology.

1 Introduction

Hand-held technology incorporating graphical, numerical and symbolic algebra capabilities has much to offer the teaching and learning of mathematics at all levels. A number of studies have investigated the use of graphic calculators in schools and many mathematics education researchers and teachers assert that graphic calculators positively influence the way that mathematics is taught as well as the content and emphases of the mathematics curriculum (for a critical review of research

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on the graphic calculator in mathematics education see Penglase and Arnold, 1996). Symbolic algebra software were introduced on computer systems in the early 1980's and were slowly introduced into the curriculum of engineering, science and mathematics courses in higher education and more widely into schools during the 1990's. The perceived threat to by-hand and mental skills did not materialise because computers were generally not used in examinations; so that traditional skills were still taught and assessed. The availability of symbolic algebra software on hand-held technology (in the form of the TI-92 and more recently the TI-89) from the mid-1990's are becoming increasingly affordable to secondary school students. These calculators have the capabilities of graphic calculators together with symbolic algebra and calculus. Most of school mathematics can now be done at the press of a button! This offers new and challenging teaching and learning opportunities and there are many issues that need investigating as these technologies are fully integrated into the curricula.

This research study investigates one of the barriers to successfully integrating symbolic algebra calculators into the teaching and learning of mathematics. Assessment schemes that ban the use of such technologies naturally discourage students. Our motivation to run this research project was to investigate student's attitudes and beliefs to using graphic calculators and those with symbolic algebra. The study reported in this paper explores some of the implications of teaching and learning mathematics in an environment where the teachers believe that the use of symbolic algebra software can help to develop understanding and skills but in which the technology is not allowed in the final examination.

Use of symbolic algebra in teaching, learning and assessment

In many countries curriculum designers, educators and examiners receive mixed messages about the role that should be played by graphic calculator technology and symbolic algebra software. In the USA the National Council of Teachers of Mathematics Standards states: "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (NCTM 2000). This has led to syllabuses, assessment and teaching approaches that actually encourage the use of hand-held technology. In France, all types of calculators, including those with symbolic algebra software, have been freely used in secondary school examinations. However contrary to the accepted opinion that such technology are tools for teaching, Trouche and Guin (1996, 1999) report that although calculators are much used by students the French academic system has not properly integrated their use. Their research suggests that no more than 15% of French teachers include graphic calculators in their teaching. In England, Wales and Northern Ireland the government agency that regulates the syllabus and assessment of subjects in schools introduced the following assessment objective: "The assessment will test candidates' ability to use contemporary calculator technology and other permitted resources (such as formulae booklets or statistical tables) accurately and efficiently; understand when not to use such technology, and its limitations. Give answers to appropriate accuracy." (QCA 2000) From September 2000 the upper secondary school mathematics curriculum was modularised so that the General Certificate of Education (GCE) Advanced level in Mathematics consists of six modules in which the examinations are externally set and marked. In two of these modules students are restricted to the use of a scientific calculator and in four of the modules students may use a graphic calculator without symbolic algebra software. In Finland, where the research study described in this paper took place, the matriculation examination is taken in the students' final year in school and the use of graphic calculator without symbolic algebra software is permitted. With such mixed message there is a need for international research collaboration to identify the appropriate use of hand-held technology and to share results with curriculum developers.

Experiences of good learning with symbolic algebra

The early work of Heid (1988) and Palmiter (1991) has been replicated by several researchers. They concluded that students using symbolic algebra software had a deeper conceptual understanding of concepts of calculus without losing traditional skills. Mayes (1996) gives a comprehensive review of research in the use of symbolic algebra software and concluded

> There is compelling evidence that fully integrating computer algebra software into the curriculum as a cognitive tool within the constructivist perspective can have positive effects on mathematics learning.
> However, if a CAS is appended to the curriculum, or used primarily as a computational aid, then learning may not be as dramatically affected.

Mayes (1994) compared a traditional lecture-based college algebra course to an experimental algebra course which stressed student involvement and the use of the computer as a tool to explore mathematics. An important part of this study was an investigation into student's attitudes towards using symbolic algebra software. He found that

> In the experimental group students' attitudes towards the use of the computer were negatively affected by the implementation. Student interviews attributed this to the student belief that they were overburdened by the extra time spent in computer laboratories. Several students commented that if the course had been worth one more hours credit, they would not have commented negatively on the implementation.

In contrast to the view that symbolic algebra software should be used throughout the learning process, Townend and Watkins (1994) argue that students should earn the right to use symbolic algebra software by the adoption of a pedagogical approach in which pencil and paper activities are used to introduce and consolidate each topic in mathematics before symbolic algebra software becomes a mathematical assistant for subsequent, more complicated exercises. Noss and Hoyles (1996) in contrast report positively on a combination of pencil and paper activities with computer based activities in teaching a topic such as proportionality. They report that the interaction between computer and off-computer activities provides a rich environment for students to explain and evaluate mathematical concepts.

Much of the research in the use of symbolic algebra software has involved the use of software such as Derive on a computer in a laboratory activity. Although the activities have often been integrated into the courseware the technology itself has not been fully integrated in the sense of homework tasks etc. The inclusion of symbolic algebra software into hand-held technology such as the TI-92 and TI-89 changes the availability of such software in teaching and learning. No longer do students need to leave ”the computer behind at school”. We can now fully integrate the software as a cognitive tool to develop concepts and skills in mathematics. But what do students believe will be the effect on their knowledge as measured by the performance indicators of the matriculation examinations?

There is a need for extensive investigations of the effective and appropriate use of hand-held technology in upper secondary school mathematics courses and to identify the barriers that still exist. In this paper we describe the findings of a research project on pupil's beliefs after they had studied a course in mathematics in which the TI-92 was fully integrated into the resource materials.

2 Purpose of the Research Study and Research design

The overall purpose of the research study was to investigate the personal attitudes of students towards the use of the technology, their perceived training needs and in their ability at mathematics when they learn using a symbolic algebra intensive environment. In particular we are interested in the barrier effects when external assessment bans the use of such technology. The topics chosen for the study formed two separate eight week courses: functions and equations (polynomial and rational functions) with grade 11 students (aged 16 years) in one school and an introduction to differential calculus with grade 12 students (aged 17 years) in a second school. The choice of different grades was to explore the effects of mathematical maturity and graphic calculator familiarity. The teachers in consultation with the researchers prepared the course materials. The Texas Instruments TI-92 calculator with built in symbolic algebra software was integrated into the course as investigations for introducing new concepts to the students and as a tool for problem solving. In each school there was an experimental group using the TI-92 and a control group using the TI-85 graphic calculator.

As it was relatively new to the teachers, the teaching approach of using investigations and fully integrating hand-held technology was also experimental. During the previous year the teachers had met regularly with each other and with one of the researchers to develop the model of teaching to be used in the course. Each teacher used the approach in their teaching during this period and reflected on their success using a report form designed for the experiment.

The aims of each course were to teach the concepts, skills and applications associated with the syllabus. One important constraint for the pupils is the Finnish matriculation examination taken by pupils in their final year in school, the performance on which decides their choice of higher education. In this examination the use of symbolic algebra software is not allowed so that it was important for the students in the TI-92 groups to develop the same mathematical problem solving skills for assessment as the other school pupils in Finland.

The research question investigated in this study was: what are the feelings and attitudes of the students when learning and doing mathematics with the support of technology that is not allowed in the final matriculation examination? This paper reports on the findings of this question.

The upper secondary school Lyseonpuiston Lukio in Rovaniemi is the largest secondary school in the north of Finland. The school consists of 690 students, aged 16-19 years, and about 40 teachers. Keminmaan Lukio is the only upper secondary school in Keminmaa. There are 230 students and 20 teachers at the school.

Typically in each school, the year is divided into five terms and the mathematics curriculum is split into modules or *courses* so that one course is completed in each school term. Students who are specialising in mathematics in the upper secondary school have the opportunity to study up to 17 courses in mathematics. Assessment for these courses is by internal school set and marked examinations. Students in Finland take a national matriculation examination in their third year of upper secondary school. This examination is externally set and marked by a small group co-ordinated by the mathematics officer at the National Board of Education.

The teaching approach used by the two teachers of the TI-92 encouraged the students to actively learn mathematics through investigations, group work and discussion rather than the transmission model by the teachers. The research methodology adopted in this study was both quantitative in that the students' answers to a Likert-type rating scale was used to collect their attitudes to their personal use of the hand-held technology and to their mathematics skills, and qualitative in that students were asked to write statements about their feelings and were interviewed at the end of the experimental period.

In Keminmaa, the same teacher taught both groups for a course on functions and equations. For these students, this was their first study of mathematics at this level. In the school in Rovaniemi, two teachers were involved, one for each class for a course introducing differential calculus. For these students, this was their sixth course at this level.

Both experimental groups used course materials written for the project whereas the control groups used a traditional textbook, a more didactic teaching style and had the TI-85 graphic calculator available as a problem-solving tool. The experimental group resources in each school embedded the TI-92 as an integral part of the learning of the mathematics in that the technology was used in investigational activities to introduce new mathematics concepts and as a tool for doing mathematics.

All four groups completed the questionnaire on student attitudes after the course. For our study it was important that we collected information about the students' attitudes as soon as possible after the course was delivered, so that the next courses did not influence their judgement. The questionnaire consisted of 25 statements that the students had to agree or disagree with at various strengths, and an open space inviting further comments.

3 Data Analysis

The goal of the data analysis was to identify any recurring themes in students' attitudes regarding their use of the hand-held technology in their course. The degree of agreement or otherwise to the statements presented on the questionnaire instrument provided data on a Likert scale which was coded 1 to 5. These data were treated as ordinal in nature.

Non-parametric statistical procedures were used to analyse the data. A 5% significance level was employed (1% was used to indicate a highly

Table 1. *Outcome of statistical analysis at group level*

Statement	All	Rovaniemi		Keminmaa	
		Con-trol	Experi-mental	Con-trol	Experi-mental
1 I can think more clearly when I use a calculator	A*	A*	U	U	A
2 Using a calculator makes me lazy	D*	D*	D	U	D*
3 Using a calculator makes me less good at doing maths by hand	U	D*	U	U	U
4 Using a calculator makes me better at solving maths problems	A*	A	A	U	A
5 I used a calculator in most of my maths lessons	A*	A*	A*	U	A*
6 I used a calculator in most of my maths homework	A*	A*	A*	U	A*
7 Using a calculator is cheating	D	U	U	U	D
8 Using a calculator helps me understand my maths	A*	A	U	U	A
10 I rely too much on my calculator	D*	D	U	D	D*
11 Using a calculator makes me less good at mental mathematics	D*	D*	U	D	D*
12 Only pupils who are good at maths should use a calculator	D*	D*	D*	D*	D*
13 I enjoyed this maths course	A*	A	A*	U	A*
14 I will do better in matriculation because I have learnt with calculator	U	A	U	U	D
16 The course material was good	A*	A*	A*	A*	A*
17 I think that the pupils who have not used a TI-92 will do better	D*	D*	U	U	D*
19 I feel better about doing mathematics after this course	U	U	U	U	U
20 I have more fun in this maths course than other maths courses	U	U	A*	U	U
21 The calculator has been used too much in this course	D*	D	D	D*	D*
22 I need more time to learn about the calculator before using it in maths classes	D	U	D	U	D
23 This maths course is different from other maths courses I have taken	A*	U	A*	U	A*
24 The role of the teacher is different compared with other courses	A*	U	A	U	A*
25 I wish to study all maths courses with the calculator	U	U	U	D	U

Note. A = Agree, D = Disagree and U = Unsure. * indicates significance at 1% level.

significant outcome), adjustment for ties was used throughout and exact critical values were employed where technology permitted.

The initial analysis to determine if there was evidence that the students as a whole held a view on a particular item was undertaken using the 1-sample Wilcoxon test with the null hypothesis H_0: = 3, against the alternative hypothesis H_1: ≠ 3. Evidence of differences in opinion between control and experimental groups were explored using the Mann-Whitney U statistic. The same analytical tool was employed in determining differences between students in the two schools. The Kruskal-Wallis statistic provided evidence of differences between the four groups of students. Both the Wilcoxon and Mann-Whitney U statistics featured in any subsequent analysis at this level in the data structure. Table 1 shows an overall summary of the results for each group of students for each statement.

The statements students wrote freely on their questionnaires are used to provide further insight into their attitudes. Not all students chose to provide additional comments – 5 students from Rovaniemi and 23 from Keminmaa.

4 Results and Discussion

The outcomes suggest that integrated technology teaching impacts in a complex fashion on student attitude. Items 12, 21, 16 and 19 indicate that the 'treatment' has had no effect. Items 22, 14, 23 and 24 indicate a positive effect Ð with maturity influencing the extent of the effect for item 14. Items 1, 8 and 17 reveal an interaction between treatment and level. Items 2, 25, 5,6,4 13 expose the young control group with a negative attitude. Items 10, 11 expose a negative attitude in the mature experimental group, whereas item 20 provides the opposite impression. Item 7 reveals a particularly positive attitude from the young experimental group as does item 3 with regard to the mature control group.

For the purpose of the research question posed in this study we are interested in the attitudes associated with external assessment schemes. Statements 3, 4, 8, 11, 14, 17 provide an insight into this question. First it is important to judge the amount of usage of the technology. Items 5 and 6 show that for three of the groups the students used a calculator in most lessons and homework. Overall, girls made greater individual use than boys in both lessons and homework. The exception to this on both counts was the young control group. Graphical calculators were not used as frequently as symbolic algebra particularly with the students new to studying mathematics at this level. All groups disagreed with the suggestion that calculators had been used excessively, and girls more so than boys.

The difference between control and experimental groups is particularly marked among the younger students. "On the Use of Calculator Technology" the younger experimental group and, at the higher significance level, the older control group believe that using calculator technology aids their clarity of thought. The experimental group may be exhibiting the benefits to be obtained from a course where technology is integrated into the teaching and learning. The older (control) group may be showing the benefits to be accrued from a prolonged exposure to the technology. This positive view is not, however, shared by their respective peers. Each of these groups is undecided about any increased clarity in thinking. The younger (control) group receive no specific training in the use of their technology. The older (experimental) group have had to change to symbolic algebra calculator after one year of studying with a graphical calculator. Overall, girls hold a more positive view than boys, but the difference is not significant at a teaching group level. Technology is an integral feature of their learning and these students perceive a teaching role for the technology. One student commented,

> " … it (TI-92) was a marvellous and great help Ð very good in checking tasks, great help in checking domains and drawing graphs. The data/matrix editor was very useful … "

Students do not rely too much on the calculator. This view is held more firmly among the young students, particularly among the symbolic algebra calculator trained group, than among the older students. In contrast, the older symbolic algebra calculator trained group are decidedly unsure about the extent of their reliance on the technology.

Students, generally, are unsure if their traditional mathematical skills are harmed by use of calculators. But the more experienced students who have been using their graphical calculators for two years are decidedly of the opinion that this does not impair their ability to do mathematics by hand. The majority of students believe that their problem solving ability is aided by the use of calculators. The exception to this is among the young control group who are as yet unsure of the effect on problem solving.

With the exception of the older experimental group who express uncertainty, students feel that using calculating technology does not impair their own mental skills. One student in the control group offered an observation on students in the peer group:

> " … I think the students who have used the magic calculator can't use their heads anymore … "

This is contrary to the opinions about themselves held by the peer group using the 'magic calculator'. This raises an issue of perceptions held by individuals of others.

On the issue of calculators helping their understanding of mathematics, there are contrasting views held in the schools between control and experimental groups. The older control group and the younger experimental group believe that the technology is a great aid. One student in the young experimental group illustrated this well:

> "It has been much easier to study with the TI-92. I have understood things better than usually. The calculator makes things look clearer."

Generally, girls are more positive about the benefits to their understanding from calculator usage; this is particularly noticed in the young experimental group. The older experimental group who are using a technology new to them and the young control group who have not received any specific training in the use of the graphical calculator are unsure of the help in understanding mathematics offered by the technology they are using.

There are contrasting differences in the opinions of the four groups concerning their individual prospects in the matriculation examination. Generally, students who used the symbolic algebra calculator – not approved for examination purposes – felt that their matriculation prospects would be harmed. The graphical calculator users, on the other hand, felt the opposite. The students who were into their second year of using the examination-approved calculator were particularly positive about their prospects. Their peers who had temporarily changed technologies were unsure about the effect that this was to have on their examination chances. The younger symbolic algebra calculator users were already concerned about the effect on their examination prospects. One commented,

> " … In the long run it is not good if you can't take the TI-92 into the matriculation … "

and, a year and a half distant form the examination, another offered,

> "… it is a bad thing that I have not learned to use the TI-85 which I have to use in the matriculation …",

whereas their peers using the approved graphical calculator did not have an opinion, one way or the other, on the effect on their own matriculation prospects.

The wording of item 17 required the student to respond on the achievement implications of students other than herself or himself: in the case of the experimental groups, they were responding about students who were studying in the other group; in the case of the control groups, their response was concerned the others in their teaching group.

The opinions of the two experimental groups were markedly different. Among the younger students for whom examinations were sometime away, those using symbolic algebra calculator decidedly did not agree with the suggestions that their peers using the approved technology would do better. This contrasts with the implication gleaned from the response to item 14, which was about their own individual prospects. The older experimental group, with the matriculation examination in sight, were as unsure of the prospects of their peers as they were of their own.

The opinions among the control groups were just as markedly but contrastingly different. The younger students were as unsure of the achievement prospects of the others in their teaching group as their response to item 14 had revealed about their own prospects. The older group were convinced that they would not do better than the symbolic algebra calculator group, in stark contrast to their vision of their own prospects.

The responses to item 17 raise a question about the appropriateness of asking students to comment on the examination prospects of others. A comment from a student in the control group in Keminmaa who strongly disagreed with item 17 supports this,

> ”The tests were too difficult … I'm happy I didn't use the TI-92 because my friends tell me they can't do maths by hand anymore …”

5 Conclusions

The process of transforming any artifact, such as a graphing calculator, into an instrument to support learning is a complex process. Such a process is called *instrumental genesis* and is described in Drijvers & Herwaaden (2000) and Guin & Trouche (1999). The instrumentation of hand-held technology tools refers to the relation between the development of the mathematical concepts and skills of using the technology. We would argue that the students in our study achieved instrumental genesis because the technology was available to them both in school and at home, in other words, throughout the mathematics module for schoolwork and for homework.

The results in section 4 provide some interesting insights into student perception and attitudes to the use of calculators in learning mathematics. Students perceive calculators as a cognitive tool which helps their understanding and clarifies their thinking as opposed to giving them an edge in examinations. The importance of mathematical maturity is demonstrated in the responses to several statements. The Rovaniemi students are one year further on in their studies so that they have studied and been assessed in four more courses than students in Keminmaa. Thus it might be too early for the Keminmaa students to deduce whether their performance in examinations and in doing mathematics by hand will be reduced. Where the maturity effect begins to show itself is whether they are using a calculator too much (item 10) in which the difference between the two schools is statistically significant ($p < 0.05$) (note that there is a difference in their views on whether using a calculator is cheating, however this is not statistically significant). The Rovaniemi students have studied courses in algebra, trigonometry, pre-calculus and differentiation and so are beginning to see advanced mathematics and the power of modern hand-held technology at being able to do mathematics at the press of a button.

One of the Rovaniemi experimental group students wrote of her thoughts regarding the change to the permitted calculator as opposed to the calculator that she had used in the course

> ”… I hope one has enough strength to study the use of the calculator for the matriculation examination ... I hope we can have clear written instructions about what is allowed and what is not.”

The experimental group in Keminmaa disagreed very strongly about being poorer in mental mathematics, agreed that using the technology helped their understanding and made them better problem solvers. But, this group were concerned that their matriculation prospects might be harmed because of the technology they were using. In Rovaniemi, where the control group had done all their studying with the examination-approved technology, they felt they would do better as a result of this.

This small research study suggests that artificially including symbolic algebra into the curriculum for a short period of time may not be an entirely satisfactory way to introduce symbolic algebra. The use of symbolic algebra will reduce the need for some by-hand skills and will inevitably challenge the traditional rules and algorithms that need to be memorised. When symbolic algebra is introduced for a short time, one difficulty for students is to decide how fully to engage with the alternate approach to learning with technology when the assessment restricts its use. It needs to be fully integrated into all class and homework activities to encourage effective learning and into the assessment schemes. Then the by-hand and mental skills that are required for the future will be fully understood and appreciated by both teacher and learner.

An important research question that needs further investigation through a longitudinal study is ”as students mature mathematically do they see technology as a barrier to performance”.

Both teachers who took part in the research study expressed feelings of pleasure and disappointment during the teaching of the courses. We finish with a paragraph from the diary of one of the teachers towards the end of the course:

> Friday afternoon after the lesson of the experimental group. I happened to ask one girl attending the course how she feels studying like this. She said that actually it has been fun. She said that usually in the mathematics lessons she is looking at her watch and waiting for the lesson to end. But now she had forgotten the watch. She continued: ”If I am saying that mathematics is fun it is really something extraordinary”. This is almost enough for me after six months' work with the material!

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Sammandrag

Att använda tekniska hjälpmedel vid undervisning och lärande av matematik kräver, bland annat, positiva attityder från elever och lärare. I den här studien har två lärare planerat och undervisat två matematikkurser i fyra elevgrupper i gymnasiet. Två av grupperna hade fri tillgång till grafiska räknare med symbolhantering. De andra två gruppperna hade fri tillgång till grafiska räknare utan symbolhantering. I artikeln redogör vi för elevernas attityder till och uppfattningar beträffande användning av tekniska hjälpmedel i en kurs där motsvarande hjälpmedel inte får användas fritt vid slutprovet. Resultatet antyder att en integrerad användning av tekniska hjälpmedel i undervisningen påverkar elevernas attityder på ett sammansatt sätt. Resultatet antyder vidare att utvärderingsformen, som en del av kursplanen, påverkar attityden mot ett fruktbart användande av de tekniska hjälpmedlen.