The Implementation of Calculators in Secondary Schools

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Recently the Mathematics Education Unit at The University of Auckland has been involved in three studies concerning calculators in secondary mathematics. Each study, for a variety of reasons, can only suggest hypotheses for future confirmation. However there are general conclusions which can be made by viewing all three studies together. Furthermore, they provide a basis for a theoretical framework for the analysis of the role of technology in mathematics education. Taken in the context of a new curriculum, the studies give evidence for the potential of calculators as a tool for developing more investigative teaching styles amongst teachers, but leave unanswered questions about the effect of these styles on children. More can be said, however, about the process of implementing technological change in the mathematics classroom. A first attempt at a theoretical model for the use of technology in mathematics education is presented for criticism.

Introduction

The Mathematics Education Unit at the University of Auckland is part of the Departments of Mathematics and Statistics within the Faculty of Science. Its teaching responsibilities lie in bridging and first year mathematics courses, and Diploma and Master programmes in mathematics education.

It also engages in research, and, in 1993, it was decided to make the role of technology in mathematics education a focus of attention. As a result, the MEU has been involved in three studies concerning calculators in secondary mathematics. One of these (Technology in Mathematics Education - TIME) is a large, Ministry of Education funded study lasting one year and involving eighteen schools. A second (Texas Instruments Research At Glenfield - TIRAG) was a one month study in which graphics calculators were introduced to three classes in one school. The third (Teachers and Calculators at Kaitaia - TACK) is an on-going study which is observing the effect on the mathematics staff and their teaching when full use of calculators becomes school policy.

In all cases the duration of the research is too short to be able to make definitive statements about the effects of technology, and, in any event, other recent research in New Zealand has shown an 18-month delay before teachers are able to integrate change into their practice (Britt et al, 1993). In the case of TIME and TACK much data is ethnographic in nature and would need to be confirmed by other researchers with other teachers. In the case of the TIRAG project, the large number of uncontrolled variables means that confirmatory research is required. (TIRAG is a joint project with the Open University in England and replication research is currently underway).

This paper will consider some general conclusions which are suggested by viewing all three studies together. Some researchers are involved in all studies, so researcher bias will remain in the conclusions. However they are useful as a basis for more detailed questions for further research.

After outlining the studies and general results, aspects of a theoretical framework for the analysis of the role of technology in mathematics education are formulated. This framework is presented in the hope that it will be critically examined and discussed by those with other relevant experience.

The Projects

TIME: An Exploratory Study

TIME is one of several Exploratory Studies (in various subject-areas) commissioned by the Ministry of Education in 1993 as part of the development of a new curriculum framework. The aims of the study are to evaluate innovative uses of technology in mathematics classes, to determine which uses are effective in which areas of the curriculum, and to determine the conditions under which students initiate the use of technology .

The project involves two teachers in each of eighteen schools arranged in three clusters. One cluster uses computers, one standard calculators and the other graphics calculators. Each cluster contains primary and secondary schools. The project has a full-time coordinator, and each cluster has two MEU researchers associated with it. Each teacher is expected, as a minimum, to have available the designated technology in every mathematics lesson with an identified class. The control of the research is with the teachers on an action research model. They decide what aspect of technology use to focus on, and how to record and analyse the data. The MEU researchers are advisors.

There are two other levels of activity within the project: cross-school integration, and extra-project integration. These levels involve other methodologies. The cross-school activity, for example, includes questionnaires initiated by the MEU research team, interviews, and group feedback sessions where common issues are discussed and explored. The methodology is both empirical in that specific questions are defined by the research contract, and naturalistic in that the research is part of on-going work. Thus new questions may arise from the data for later confirmation or investigation. The extra-project activity integrates TIME results with those of other studies. This could be considered as the literature review for the project, but it also integrates work which is being conducted in parallel. In this sense the methodology is theoretical/naturalistic: research questions are derived from individuals' experience and their theoretical base is matched against the empirical outcomes of various studies. The result is redeveloped theory and redeveloped experimental studies.

The TIME Project is in its writing-up phase (April, 1994). There is considerable evidence for the power of calculators to encourage the exploratory study of mathematics and to reduce dependent mathematics learning. Teacher concerns include the recording habits of students. Other results relate to the implementation of technology, and to technological imagery. Further methodological details and findings are available in the Project Report (MEU, in preparation).

TIRAG: A Graphics Calculator LINK

This short study was conducted by Bill Barton (MEU) and Alan Graham (Centre for Mathematics Education, Open University) as part of a British Council LINK programme. It was the first in a series of studies aimed at identifying whether the method by which technology is introduced to students affects the ways in which it is subsequently used, and the type of learning which results. This pilot study is being replicated in England, after which further projects on the same issue are planned. Texas Instruments provided the calculators on loan for the study.

TIRAG involved introducing graphics calculator technology to three junior secondary classes, each in a different way. One class was allowed free exploration; one used a structured, peer-tutoring system; and the third had a didactic, teacher-led programme. The introduction took place over 6 sessions, during which time all classes were preparing for an end of year test (in which the calculators would be permitted). After each period students were asked to fill in prepared log-sheets. A seventh session (identical for all classes) involved a revision worksheet of sample test questions, and the researchers recorded calculator use and the type of questions asked by students. All sessions were led by the researchers, although the teachers were present as assistants. Teachers were also asked to record their observations, and were given the opportunity to visit other classes.

The methodology for TIRAG was formally empirical, with a pre-determined overall question. However, because it was a pilot study, no attempt was made to control class variables after the initial selection of broadly similar classes. Part of the purpose of the study was to identify possible parameters which would be worthy of more tightly controlled research. The results indicated an interesting difference in the attitudes of students in different classes, and in the use of the calculators by the free exploration class compared with the didactic class. Small gender differences were noted. The full report may be consulted for further details (MEU, 1994).

TACK: Full Implementation

In late 1993, the MEU received news that a large Northland secondary school was bulk-buying SHARP EL531 GH calculators so that every mathematics teacher had a class set. The MEU offered to help run calculator workshops for the Mathematics Department in return for their partnership in a research project aimed at monitoring the changes within the Department, in teacher attitudes towards technology, and in mathematics teaching styles.

The first workshop and data collection took place in the first week of school, 1994, the second at Easter, and a third will have taken place before July 1994. Four further sessions are planned. It is hoped that the research will indicate needs, opportunities and problem areas for schools wishing to make full use of technology in mathematics classrooms.

General Results

As mentioned above, none of these studies is rigorous enough to make definitive statements with confidence. However, the following results can be identified as common to all three studies and are therefore more likely to be useful. These provide a basis for further research.

Implementation

Access - In all three studies, access was the critical variable which made the study different from normal classroom practice. Calculators were available to all students in every class, and the teacher could plan around a particular model. In both TIME and TIRAG, teachers saw this as such an advantage that they expressed concern at the inequity of providing such access to some students in the school and not to others. Although there was some evidence for actual achievement advantages (see below), a perceived advantage is sufficient to affect the morale of students and teachers, and would worry parents of those students thought to be missing out.

Ownership/Cost - In all three studies the use of calculators on a full class scale prompted both schools and students to purchase their own similar calculators. In TACK, sales of calculators to students increased dramatically despite the fact that, for the first time, they were provided as class sets by the school. Several students in TIRAG and TIME bought graphics calculators privately, and several schools were prompted to invest in a class set. It appears that private ownership is preferred (presumably so that calculator use can extend outside the classroom). Cost is not prohibitive for individuals or schools, whether calculators are purchased is a question of awareness and priority.

Teaching Styles

Student Control - All three studies provide evidence that effective use of calculators goes hand in hand with passing control of the learning situation from the teacher to the students. In TIME the graphics calculator teachers were given overhead projection models to use. All teachers who attempted to use them abandoned the attempt as inappropriate after two or three lessons. In TIRAG the class which was most under teacher control was most locked onto questions about the calculator (rather than questions about mathematics) in their observation session. In TACK the anecdotal accounts of significant events are so far all concerned with lessons in which "letting go" was a feature. This feature of calculator use is echoed in the C^2PC study (see Waits et al, 1993, p21).

Exploratory Teaching - The studies have all produced materials for use with calculators. It is noticeable that all those materials which have developed beyond single worksheet stage have a significant component of student exploration. This may be because investigation is a focus of the curriculum (Ministry of Education, 1992). In TIRAG the worksheets which provided most on-task activity were those which presented mathematical problems and invited solution using the calculator.

Effects on Learning

Motivation - All three studies provide additions to the growing evidence for the motivational power of calculators (Hembree et al, 1992). Positive effects were noted across all students: male/female, senior/junior, top stream/bottom stream. Students and teachers were aware in all cases of jealousy amongst other classes, and even, in the case of TIRAG, between two classes using different types of graphics calculator, one of which was perceived to be superior. Classroom control did not turn out to be the difficult issue some teachers anticipated, on the contrary, in one TIME classroom behaviour improved dramatically with the introduction of calculators.

Students' Imagery - An effect noted in all three studies (but not found in any of the literature surveyed) was the development amongst the students of a calculator culture, usually including imagery or jargon prompted by the calculators. For example: some students in a TIME class using graphics calculators began setting out their calculations left justified and the answer right justified on the page, as on the large screen. In a trigonometry class the solution to right-angled triangles was described by button sequences on the calculator. In a TACK class students exploring fractions began to refer to the [a b/c] button as the "Silly Button", and all subsequent discussions on fractions used this term. Perhaps not significant in themselves, these incidents are reminders that the power of technology is not just its utility, but its ability to transform the way we think.

Achievement - There was some evidence that students with the calculators performed better than their peers. However, as in a comprehensive American survey (Hembree et al, 1992), no large significant increase could be claimed. This issue is closely linked to assessment, but in two situations in TIME where parallel tests were monitored between calculator and non-calculator classes, the calculator class performed better. In several instances, teachers recorded concern that students using calculators would perform worse because they had 'wasted time' learning how to operate them instead of doing mathematics. In fact, in TIRAG, students quickly began to pose and explore their own mathematical questions.

Effects on Curriculum

Order - Particularly in TIME, where teachers are working with calculators over an extended period, but also in TACK and TIRAG, there have been many significant changes to the order in which teachers have successfully covered topics. For example: promoting graph work so that it can be used in beginning algebra; and making random numbers an early probability concept.

Content areas - In line with much of the literature (e.g. Burrill, 1992), there have been new topics introduced and other topics dropped. For example teachers using graphics calculators de-emphasise algebraic solutions to quadratic functions, and emphasise rounding errors and graph scales.

Assessment - In each of the three studies, assessment has become a critical issue for teachers and students- usually late in the study after teachers have made significant changes in their teaching style or content. The realisation that a different mathematics is being taught brings concern about equality of opportunity in conservative national examinations and cross-school tests.

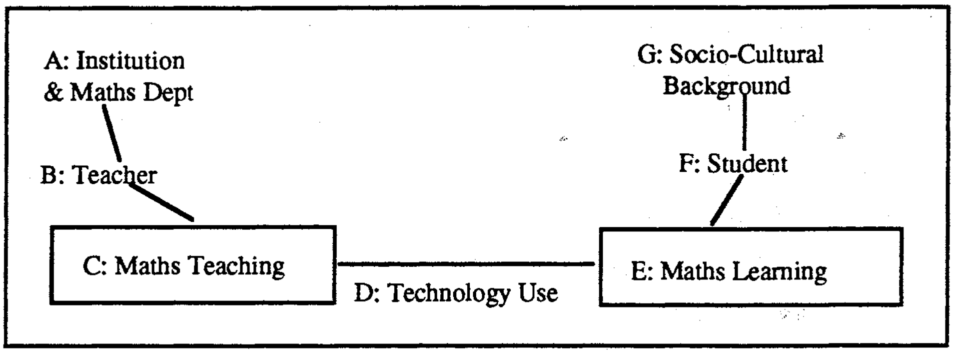
Teacher Development

The studies have provided a wealth of information about implementing technological change in mathematics classrooms. The importance of the teacher in this process is vital. Teacher attitude was the most important uncontrolled variable in the TIRAG study, and is the major focus of attention in the other two projects. The main findings are that the critical aspect of teacher development is the realisation that mathematics teaching using technology is fundamentally different. Teacher skill with the calculators, resource production, and management issues are of secondary importance.

Towards of Model of the Use of Technology in Mathematics Classrooms

There are two aspects to the role of technology in mathematics education: the implementation of technology, and its effect on learning. The framework below relates to the first of these.

The research studies detailed above suggest two opposing types of questions about the use of technology: one set of questions relates to those things which promote effective use (as judged by teachers); and those things which inhibit effective use. This dimension "technology conductance / technology resistance" was derived from the reactions of teachers during the studies. It was quickly realised that the teachers were not the only source of conductance and resistance, they were just the source the researchers were closest to. The following framework is an attempt to map other sources:



It is assumed that the use of technology is a mediator between mathematics teaching and mathematics learning. Other mediators in this sense are texts, classroom environment, curriculum, and assessment. These mediators may act in conjunction with each other. Mediators have potential to change mathematics learning in positive and negative ways. They are not neutral. Technology Conductance ($T\Sigma$) refers to the ways technology can be positive in its effect. Technology Resistance ($T\Omega$) refers to the ways technology can be negative in its effect, including inappropriate uses and blocks to its use. $T\Sigma$ and $T\Omega$ can be sourced in any one of the sites in the diagram. The examples below are all examples from the studies above.

Technology Conductance ($T\Sigma$)

An example of Institutional $T\Sigma$ is the provision of teacher development opportunities, Teacher $T\Sigma$ includes modelling calculator use in the classroom, Teaching Style $T\Sigma$ could be adapting assessment tools to promote calculator use, Learning Style $T\Sigma$ is exhibited in the inquisitiveness of some students, Student $T\Sigma$ includes showing other students what has been discovered. An example of Background $T\Sigma$ is the technology familiarity of students through videos and computers.

Technology Resistance ($T\Omega$)

An example of Institutional $T\Omega$ is lack of financial priority to purchase equipment, Teacher $T\Omega$ includes intimidation of the mathematics inherent in the technology, Teaching Style $T\Omega$ could be the use of calculators to complete pages of sums, Learning Style $T\Omega$ is exhibited in the calculator dependence of some students, Student $T\Omega$ includes such things as fear of breaking the machine or being shown to be ignorant, or the example cited in Ruthven's research (1992) of students losing control of the mathematics. A familiar example of Background TΩ is the parental attitudes which regard calculators as inhibiting mental arithmetic.

Future Research

The results cited above can now be reposed as research questions using the TΩ/TΣ framework, e.g.

- In what ways do different models of calculator in one class inhibit their use? (D)
- How does use of school-supplied calculators differ from privately-owned calculators? (D)
- Is student control an essential factor in effective calculator teaching styles? (C)
- Are all students equally motivated by calculators? How long will this effect last? (F)
- Is calculator imagery an example of TΩ or TΣ? (E)
- How can a students thinking be recorded or assessed when using a calculator? (C)
- What are the dimensions of Teacher TΩ and Teacher TΣ? (B)

Summary

The Mathematics Education Unit has embarked upon a long-term programme to investigate the role of technology in mathematics education. As a first step it has taken up three opportunities to conduct small-scale studies. Although each is too small to be useful in itself, taken together they have provided some common results, and enough information to design a framework for analysis. This framework can be used to re-express the results as research questions for future work. Critical analysis of the framework, and of this process is sought.

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