Small software for mathematics on hand held technology.

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Introduction

The introduction of interactive whiteboards into classrooms has seen an increasing use of ICT by teachers. However, this may mean that students are getting fewer opportunities to use ICT individually or in small groups (Smith et al, 2006).

"54. Several years ago, inspection evidence showed that most pupils had some opportunities to use ICT as a tool to solve or explore mathematical problems. This is no longer the case; mathematics makes a relatively limited contribution to developing pupils' ICT skills. Moreover, despite technological advances, the potential of ICT to enhance the learning of mathematics is too rarely realised."
'Mathematics: Understanding the score' (Ofsted, 2008)

The project investigates the impact on teachers and students of the introduction of small software applications on handheld technology in the mathematics classroom. It also investigates the issues raised by the addition of a networking facility to this technology which allows students and teachers to share an interactive space.

Background

Small software which is sharply focused on specific topics is well established as a useful resource to support learning in mathematics. Specific examples include the SMILE software (www.bebc.co.uk) and ATM programs. (www.atm.org.uk)
Hand held technology like powerful graphical calculators (GCs) are now able to run versions of this software and a wide range of software is now becoming available for them.(e.g.: http://education.ti.com/educationportal/sites/US/productDetail/us_smile_83_84.html and www.calculatorsoftware.co.uk) GCs are often regarded as being mainly used for graph plotting but this is just one dimension to their functionality. (Hennessey, 1999; Wright, 2004)

As the Ofsted report demonstrates, teachers are adopting ICT in the form of projection technology and 'interactive whiteboards', but fewer are expanding access to the technology to the students and where this happens it frequently involves the booking of a special 'computer lab', reducing the frequency and 'ad hoc' use of ICT as part of the mathematics classroom.

“56. In the secondary schools, the two main problems were the lack of ICT resources and weaknesses in identifying suitable activities at key points in schemes of work. “ Ofsted 2008

Research into the use of GCs in the classroom in the UK and elsewhere is developing, (Burrill et al 2002).
See (http://education.ti.com/educationportal/sites/US/nonProductSingle/research_bibliography.html) for a collection of research papers on GCs.
There is also a growing research programme investigating generic hand held devices in education (Perry, 2003). (See http://www.handheldlearning.co.uk/ for more information about educational uses of handheld technologies)

This project

The study is a two year enquiry which began in June 2007 with the delivery of the GCs and was completed in March 2009.

The study focuses on the introduction of two class sets of TI84 GCs together with a range of software and supporting accessories into the teaching and learning practices of a secondary school mathematics department. The school involved is an 11-18 mixed comprehensive specialist mathematics and computing school of approximately 1600 students. Use of the GCs was concentrated in two top set Year 8 mathematics classes. In one class students were each given a GC to take home during the first year, while in the other class the GCs were used in school only. In the following year no students had personal ownership. The intention was to consider how the personal ownership of the GC and the chance to use it out of school affected learning. This arrangement also allowed the teachers to make use of the class set of GCs with other classes and for other teachers to use them.

The teachers were supplied with a GC emulator (TI Smartview©), which allowed them to model the GC on their pc and project the image on to a whole class display, facilitating explanations and the modelling of procedures. A later addition to the project is a networking system, the Navigator, which allows the GCs to be linked to each other and to the teacher’s PC so that data and images can be shared and ‘screen shots’ from the GCs projected on to the whole class display.

The initial approach to the use of the technology via small software was chosen as the most accessible and motivating route into its use. This approach was chosen since we hypothesised that the adoption of new technology by teachers and learners is most successful where it does not involve a big commitment initially in learning about its functionality, where the application fits in well to teachers’ existing practice and where there is an immediate gain in ‘value added’ to the learning of the students. However, we were aware that this approach may lack challenge and fail to have an impact on classroom practice. Thus some episodes of outside training were also offered.

The two mathematics teachers centrally involved in the project were interested in the potential of the GCs, but had no previous experience of using such technology in their teaching. They were given GCs and some initial training (mainly focused on how to load and run small software on the GC) in the summer term 2007, then used them in class from September 2007. The Navigator networking device was delivered to them during this first term and they received training on it in February 2008 and began to use it in their lessons from that date.

The teachers kept diaries recording their reactions to the innovation.

Development of the project

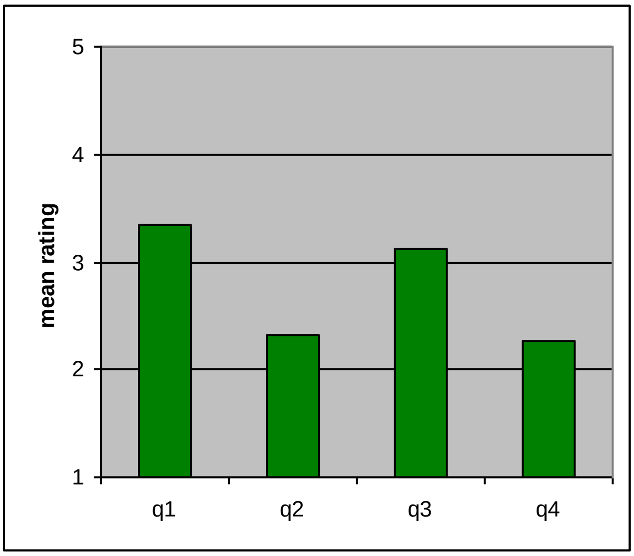
Throughout the project CfLaT researchers have worked with the teachers and students to investigate their experiences of using the handheld technology for mathematics teaching and learning. Data has been gathered through informal interviews and meetings, classroom observation, teacher diaries and pupil questionnaires. At the end of the first year classes were restructured, with some mixing of the students. At this point the GCs were taken into the ownership of the teachers. Class 2 (in the second year) contains a majority of students who had experienced personal ownership.

Impact in the classroom

Learner's perspective

Students in the two study classes completed short questionnaires about their experiences with the GCs in November 2007 and June and December 2008. The answers to the first of these provides an impression of early usage, reactions and opinions.

The opening questions were worded as follows:
1) How interesting do you find maths lessons with the graphical calculators (GC)?
2) How interesting do you find maths lessons without the GC?
3) How enjoyable do you find maths lessons with the GC?
4) How enjoyable do you find maths lessons without the GC?
They each required indications on a five point scale, running from 'very' (enjoyable or interesting) to 'not at all'. As can be seen below, students tended to rate lessons with the GC as being both more enjoyable and more interesting than those without:



Mean responses from students to questions 1-4 (Nov 2007)

These differences are statistically significant (Wilcoxon Signed Ranks Test, $p<0.001$), showing an initial, consistent perception among the learners that the use of the GCs in their lessons was beneficial. This impression was supported by observation of lessons, including informal comments made by the students, and corroborated the opinion of the teachers that the GCs were generally well received by their classes.

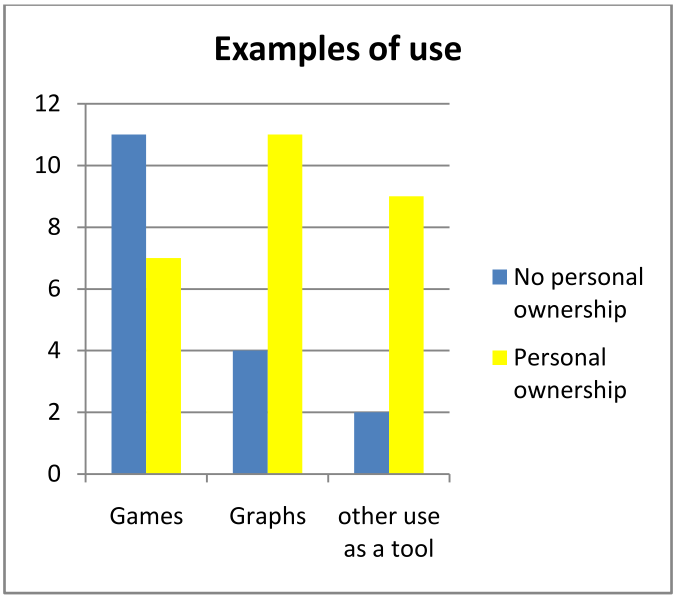
It was anticipated, however, that the GCs would have a wider impact on learning, perhaps stimulating problem-solving and higher level talk around mathematics. During the observed lessons much of the talk between teacher and learners and between learners seemed to concern the practicalities of using the GCs (e.g. *"Where's the timer*?") or specific, fairly low level requests for help (e.g. "*What's 0.98 x 9*..?").

During later classroom observations, a higher proportion of comments related to mathematics were noted. For example, in a lesson using the graphical functions to explore equations of lines, which took place in mid-March 2008, learners were heard discussing each others' graphs, asking nearby students "*How did you get that*?" and offering ideas to the teacher:

"If you divided by 2 would it be, like, the other way round?"

These observations support the frequently reported impact of the effectiveness of ICT in promoting conjecturing and experimentation. However, it needs to be noted that these are taking place in the context of the normal mathematics classroom, not a 'computer lab'.

It was also anticipated (see the later discussion on 'instrumentation'), that some students would begin to use the GC as a 'tool' as well as a way of running small software. The following responses appear to demonstrate that those students who had personal ownership were certainly more aware of this aspect of the GC. (In response to the question 'Give an example of something you've found the GC can do'.



December 2008

Difficulties

The *initial* challenge of navigating around the GC was mentioned by many of the learners in response to a question on the questionnaire asking them "What, if any, difficulties have you had using the GC?":

"It's very complicated to get on to each program"
"Getting lost in the menus lots of things to remember"
"remembering how to clear ram and to get programs on"

It needs to be acknowledged, though, that these comments were made in November 2007, when the learners were still relatively unfamiliar with the GCs.

Later comments (December 2008) from students demonstrate that about half recalled some practical difficulties, but half said they had no difficulty using the GC.

Teacher's (initial) perspective

The teachers' initial reactions were favourable and the teachers found the training on how to access the software particularly useful.

'*Very helpful session, I feel less intimidated at the thought of using the calculators in the classroom with the students. The programs we saw were excellent and I am looking forward to using them with the students'.*

'seems at the moment to be a wonderful resource!'

The potential for students to progress at their own pace was noted;

'it was excellent for the higher ability pupils especially as they could progress at their own speed'

It also seemed to motivate the students to work on what could be quite ‘dry’ material (arithmetical operations):

‘pupils probably did more examples than they usually would have’.

The unfamiliar resource also caused some problems:

‘I am not able to get round the room quickly enough to support each pupil as soon as they need help. Extra staffing would be nice’.

‘I felt the lesson was a bit stressful as some pupils could not progress due to technical problems’.

This suggests that extra support should be made available when GCs are introduced so that teething problems can be quickly dealt with. However, these issues were outweighed by the initial positive impact in motivation and enjoyment in learning afforded by the introduction of the GCs.

‘I feel [the] motivation of [the] class and overall pupil enjoyment of maths has increased dramatically using the calculators. Especially effective for engaging boys who sometimes do little work in the lesson!’

Teachers quickly noted that there was a need for another style of pedagogy in using this facility.

‘*I found the program is good for testing understanding, but I found it hard to assess pupils understanding during the lesson due to pupils being asked different questions.’*

Note though, that in contrast to a similar exercise using written work, the students are no longer able to give each other ‘the answer’ without engaging in some level of problem solving. Further work with students to reflect on how engage in peer support in these situations could increase this level of interaction.

Later diary entries, particularly in the class where the students have ownership of the GC, suggest that the initial novelty has ‘worn off’ so that more attention needs to be paid to the appropriateness of the activity.

‘The lesson was ok, but I’m now feeling that familiarity is breeding not contempt, but certainly the novelty is wearing off and some pupils are not working as hard as they could be.’ [However, it should be noted that a classroom observer comments that the proportion of on-task behaviour generally remains ‘pretty high’ even when there are problems.]

Additional benefits of access to this resource that were noted included the flexibility afforded so that students who had been absent could be introduced to the resource and catch up at their own pace.

There was some additional difficulty in developing the use of the GC as a ‘tool’ which supported the students’ thinking, because both the teachers and students were unfamiliar with this aspect of the technology. However, many students remarked on the graph plotting facility as something they recalled from using the GC. The technology also had its own limits, for example, it was not possible to plot the graphs of ‘implicit’ functions without students transforming them into the ‘y =’ format which caused extra problems when students were unable to perform the transformation accurately.

Extra training on this issue was given in February 2008 and teachers began to incorporate these features into their lesson planning.

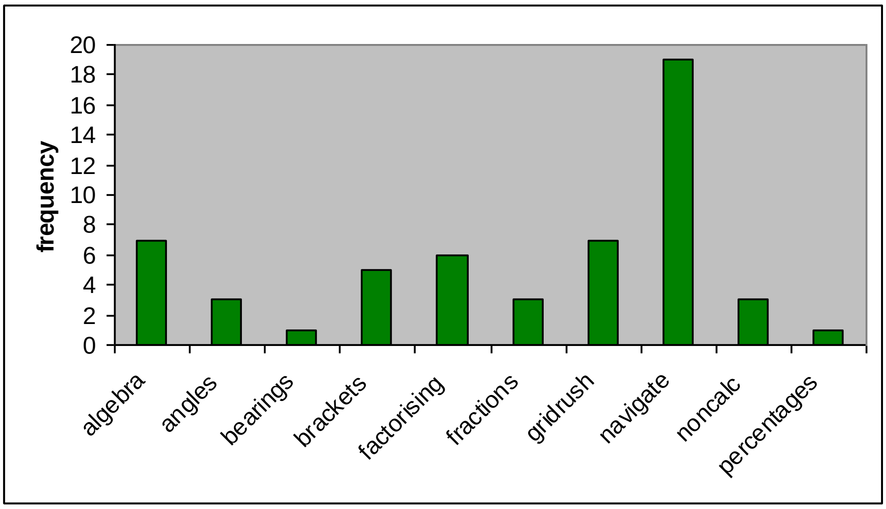
Use of ICT for learning mathematics

Learner’s perspective

As mentioned above, there are concerns that although ICT is present in the contemporary mathematics classroom it is often limited to the IWB, and so mainly used by the teacher. In this respect the provision of handheld technology for learners makes a clear difference. The earlier observed lessons used the Non-calc (*www.calculatorsoftware.co.uk*) program to first practice operations on decimals and, in a subsequent lesson, to revise understanding of fractions. In these sessions the GCs functioned essentially as textbooks, with the notable advantages of providing different problems to each learner, giving instant feedback, stimulating further challenges (going up a level and a timer) and reducing desk-top clutter. Although this use of the GCs was not particularly mathematically sophisticated, the learners seemed motivated by this way of setting problems. They enjoyed the challenge of completing levels and comparing their times and accuracies, which the program recorded for them:

"timing is fun against friends"
"I like the games and they help you learn the topic"

The student questionnaire included the question "Give an example of some maths work that you've done using the GC in a lesson". The responses to this request (see below) demonstrate that, at this fairly early stage, the GCs are being used for a variety of mathematical topics:

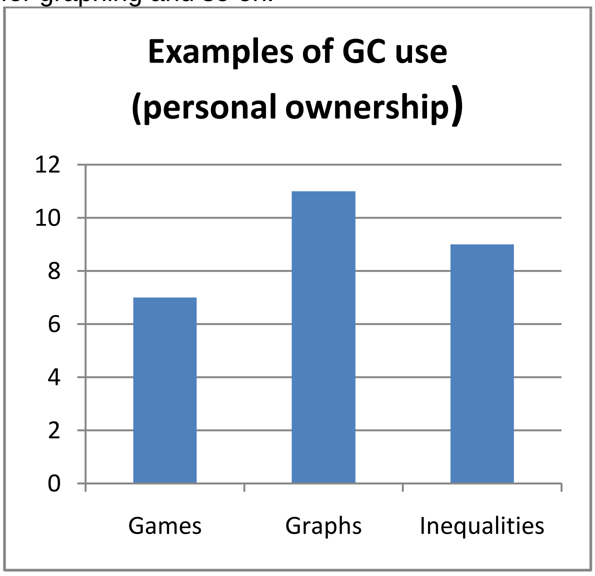


June 2008

Responses from the students to "Give an example of some maths work that you've done using the GC in a lesson"

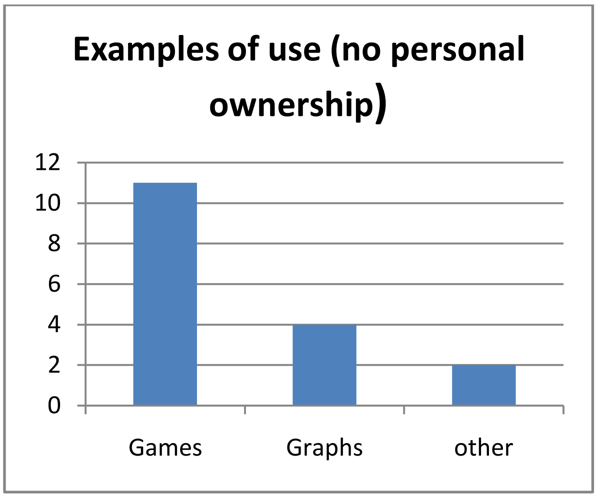
It is notable that although some learners refer to the programs by name, others have remembered mathematics which they covered using the GC. It would appear therefore that the technology is not totally obscuring the mathematical content.

Later responses demonstrate that the GC is also being used by the students as a mathematical tool for graphing and so on.



December 2008

However, this development was limited where students did not have personal access to the GC.



December 2008

As far as perceiving the GCs as technology is concerned, other comments on the questionnaires are revealing. In response to “Is there anything else you’d like to tell us about using the GC?” students wrote:

“Not all the games are fun but better than normal lessons (except with the laptops)”
“…why can’t you just have a clear ram button! It’s a brick! & very heavy”
“It can be quite boring because it doesn’t have graphics (or good ones)” (June 2008)

Although one of these respondents clearly felt that using the GCs for mathematics was in some ways similar to using laptops, and so more enjoyable, there are clearly some perceived problems. Talking to the students during the early lesson observations also produced remarks about the awkwardness they found with the GCs. Despite being a generation familiar with technology, many learners got lost on the menus and felt confused. Perhaps this is not technology as they’ve become used to it: one student responded to his teacher’s GC-computer analogy by saying that the display, with its initial blank screen, did not look like any computer he’d ever seen.

Students were also frustrated by comparing the functionality of the GC with other mobile technologies:

“we should be able to have internet access with it and have games like chess and checkers” (December 2008)

(However, these functions may be ones which teachers might regard as distractions from the purpose of doing mathematics. This lack of functionality avoids the problems which arise with the use of laptops in class where the difficulty of controlling students’ access to inappropriate content can be encountered.)

The ‘TI-Navigator’ network

In these earlier lessons the learners were always working individually on their own GCs. Later lessons involved the use of the Navigator© networking device.

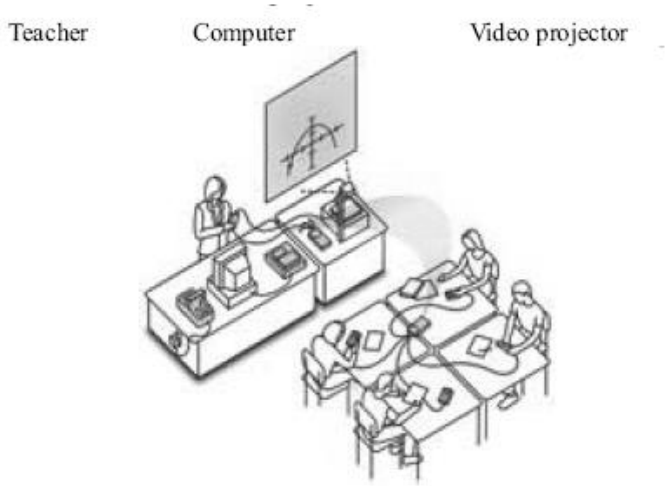


Figure 1. *TI-Navigator in the class*

In observed lessons this was used both to collate contributions from students towards a shared displayed result on the IWB and to display results of each class-member’s work as a series of screen-shots. This use of the Navigator produced some instances of ‘interactive whole class teaching’, as well as learning, which seemed generally to engage all the learners.

This system appears to have the potential to transform the way in which mathematics is taught and learnt. The teachers and students can send and share data and programs through a ‘hub and spoke’ system, where the data and programs flow through the teacher to the students.

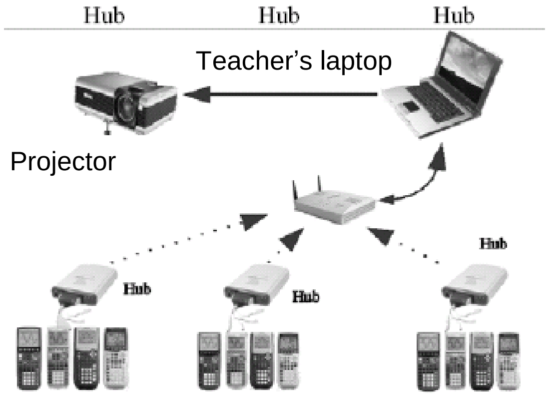


Figure 2. *Equipment arrangement*

Teachers are able to get instant assessment feedback from the students by using a variety of multichoice ‘polls’ or by displaying the students screens either individually or collectively through projection. Data from the polling can be stored and used later to review the lesson.

In addition, an interesting facility allows all students to share an interactive ‘projected’ space, where they can simultaneously control cursors or plot graphs. An important aspect of the system is that it is difficult for students to ‘opt out’ invisibly, but their contributions are anonymous (although the teacher could identify the students if needed). This potentially encourages a fruitful conjecturing and anxiety-free atmosphere in which to do mathematics.

Further details of the system are available at: http://*education.ti.com/navigator*

Since there was only partial training available for using the Navigator network, this impacted on the use made of the system in the classroom. Teachers found the technical and administrative burden in setting up the system onerous and this prevented their using it frequently enough for students and themselves to become fluent in their use of the system. Unlike the introduction to the small software, this meant that the teachers did not really ‘own’ this development during the scope of the project.

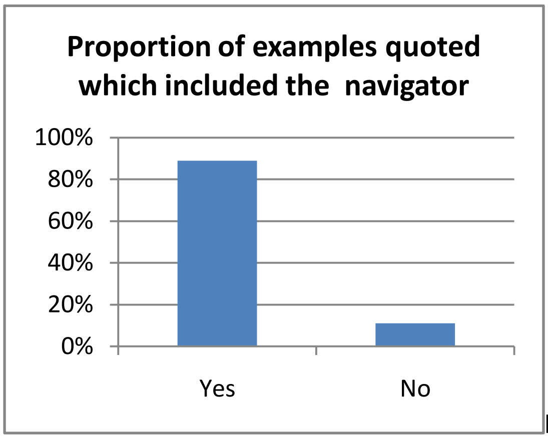
However, there were some lessons where the system was used extensively. For example, we observed that during lessons which involved investigating linear graphs, and used the Navigator, learners were able to look at and share the graphs they had managed to produce through inputting equations, in the context of results from others. The display of screen shots allowed them to see how others were rising to such challenges as the teacher’s request to produce a horizontal line and facilitated discoveries through discussion, such as about the quadratic curve that one student had accidentally produced.

We observed that the Navigator was also used to collate points entered by the students, according to a given rule, to produce the loci of a line on a single set of axes on the IWB. This clearly appealed to the learners, who responded quickly and made comments such as “There’s mine!” This introduction to the relationship between equations and graphic representations resulted in engaged discussion between the teacher and individual learners, as learners tried to describe what the results of varying the equation would be.

However, there were also issues arising from students inputting erroneous points, initially by accident, but then on purpose. The teacher found this disconcerting and curtailed the activity. Thus the most engaging and interactive use of this technology also makes it possible for learners to ‘derail’ the lesson, since the genuine collaboration depends on their cooperation. This is an area of pedagogy where teachers were essentially on new ground and could be a key issue on which to focus further professional development. A subsequent literature review shows that research (Hivon et al, 2008) indicates that this is a stage students need to encounter and explore in order to ‘own’ the system.

The network also has the facility for providing instantaneous assessment feedback through a ‘quick poll’ where students respond to a variety of multichoice or free text entries. However, teachers did not appear to use this apparently powerful feedback function. Whether this was due to unfamiliarity with the technology or some other issue is not clear.

However, the partial use of the system was enough to make a significant impression on the students who chose an activity with the navigator frequently when asked to recall something they did with the GC.



December 2008

Students' comments on the Navigator:

"I think it's good because the teacher can see everyone's work"
"It's great finding who's right and wrong"
"allows everyone to participate in activities"
"you could see what we doing"
"it gets everyone involved"

However, some students noted that the use of the system put a strain on classroom organisation:
"there's too much cefafel"[sic]
"It is a good idea but you keep having to refresh the screens"

One student was concerned about displaying their work even though they were anonymous:
"I don't like my answers on the board in case its wrong"

Teacher's perspective on the use of ICT

The teachers are developing their experience in how and when the use of this technology might be appropriate. The first term's activities mainly consisted of using the GCs to run small software and the teachers recorded a range of reactions to this resource:

Some very positive remarks were recorded:

'Used solving equations program – excellent'; 'Massively successful!, Kids loved it and progressed very quickly through the 12 levels.'

Other judgements were more measured:
'I think the functions are far too hard for Y8 to manage, and are beyond the scope of what is required at even GCSE level!'

'If I had to teach this again I would start with 'old fashioned' methods, then use the calculator as a consolidation tool and/or a way of extending the topic.'

'I found the program is good for testing understanding, but I found it hard to assess pupils understanding during the lesson due to pupils being asked different questions.'

This demonstrates that, despite the immediate impact of the technology on teaching and learning, professional judgement and experience was being developed to support decisions about when, how and whether to use this resource.

As the project progressed the teachers began to be curious about the range of functionality of the GCs and the potential of the networking facility. The training offered in February addressed both of these issues and introduced the teachers to some ready-made classroom activities which could be used with minimal development. This input was very well received:

‘*We were ‘fired up’ again, and were impressed with how the calc’s can be used to explore accuracy, fractions, standard form and algebraic identities.’*

There are a range of issues for further professional development here. Evidence from the teachers’ diaries noted that, despite their growing familiarity with the GCs, the learners’ response varied widely according to the choice of activity and resource used. Some activities were extremely popular and students returned to their use voluntarily either in the classroom or at home. Hence there is a need for both for teachers to become more informed about the potential pedagogical value of particular activities and also to be able to judge what that potential might be in the context of the GC and how and when to mediate and intervene in the students’ activities.

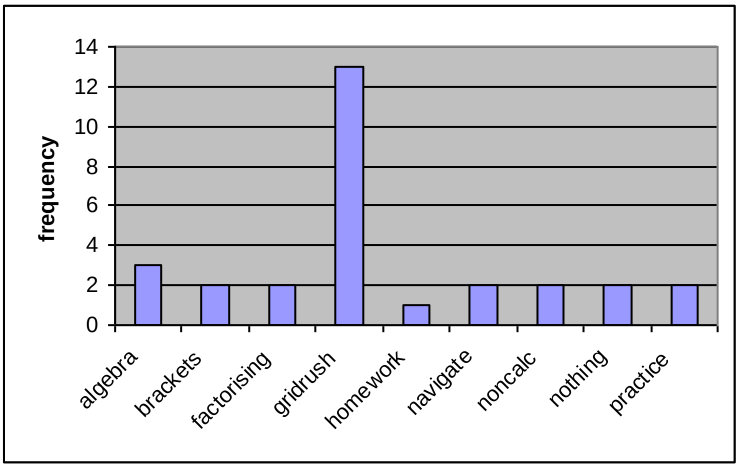
Practical issues in using the networking system are being explored. One significant issue was that it was discovered that the arrangement seemed to be modelled on the teacher remaining near the pc. (In order to control the ‘screen capture’ facility) This had the disadvantage that the teacher had to keep returning to their workstation in order to refresh the class display, which interrupted their work with individuals or small groups of students. This situation was resolved through the supply of a remote ‘gyroscopic’ mouse which allowed the teacher to operate the pc from anywhere in the classroom.

Personal ownership of technology

The design of this project, with one class-set of GCs and the other class having their own, was intended to investigate the effect of personal ownership. It was questioned whether more access to the GCs themselves and chance to use the software might benefit students’ mathematics learning.

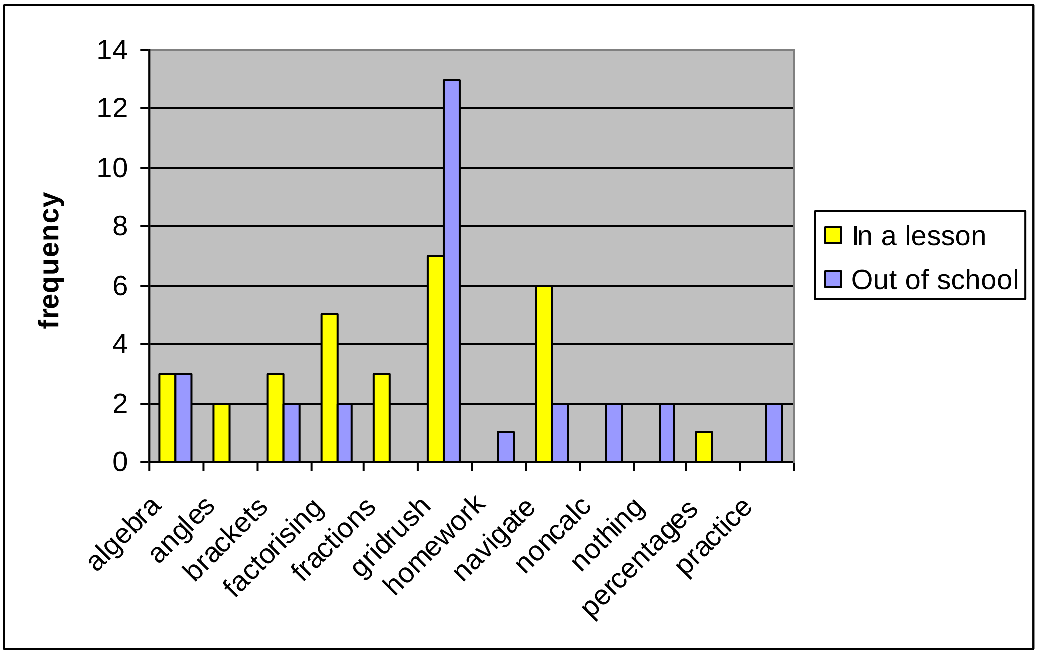
Learner’s perspective

A first step to this objective would be the students actually making use of the GCs out of school, and to assess this, the questionnaire to members of the class taking home GCs asked for “an example of something you’ve done using the GC out of school”. This was in addition to the item, included for all the students, which asked for “an example of some maths work that you’ve done using the GC in a lesson”. As can be seen from the bar chart below, the students who took home the GCs were able to provide examples of using them out of school.



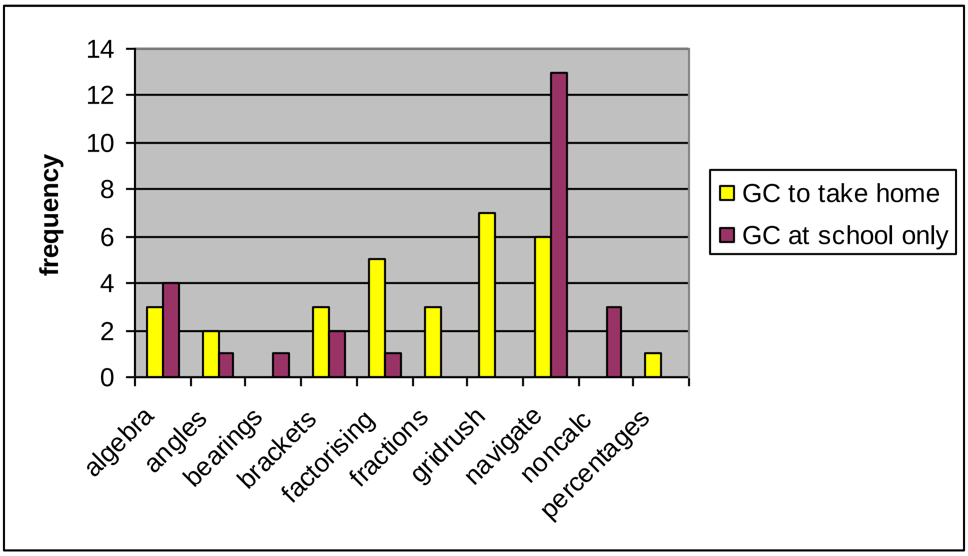
Learners’ examples of how they have used the GCs out of school (June 2008)

Only one learner reported this as ‘homework’, while a further two said they’d done ‘nothing’. Most of the students were able to give examples of either mathematics areas or programs they had used, with Gridrush (a timed numerical skills game) clearly proving popular. The examples given by these students of GC use out of school relate to the uses they remember from lessons (see bar chart below), but the many references to gridrush suggest they are choosing to play this game independently.



Learners' examples of how they have used the GCs in a lesson and out of school (June 2008)

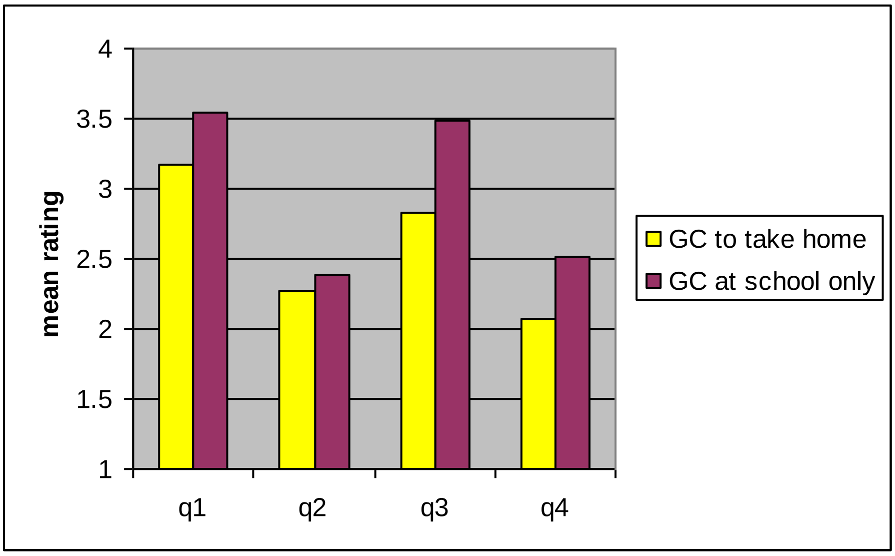
It is interesting to compare the responses from the two classes to the request for an example of some mathematics work in a lesson using the GC. As the bar chart below shows, there is some tendency for the learners with their own GCs to recall a wider variety of uses, despite the fact that lesson content for the two classes was virtually identical:



Examples from members of the two classes of how they have used the GCs in a lesson (June 2008)

There seem to be some differences in how the members of the two class rate the enjoyment and interest of the mathematics lessons, as shown by mean responses to the first four questionnaire items:

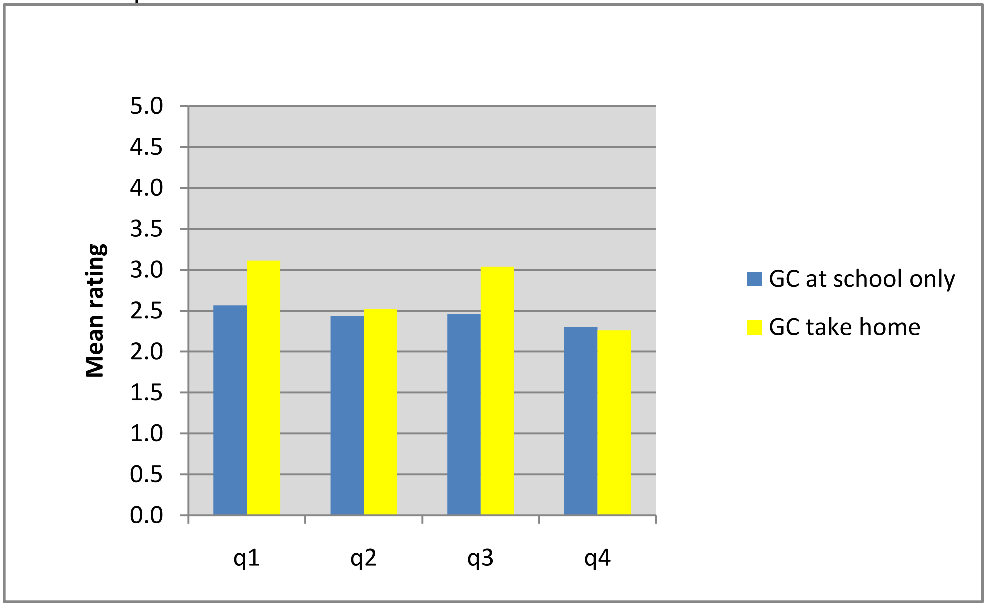
1) How interesting do you find maths lessons with the graphical calculators (GC)?
2) How interesting do you find maths lessons without the GC?
3) How enjoyable do you find maths lessons with the GC?
4) How enjoyable do you find maths lessons without the GC?



Mean responses from students in the two classes to questions 1-4 (Nov 2007)

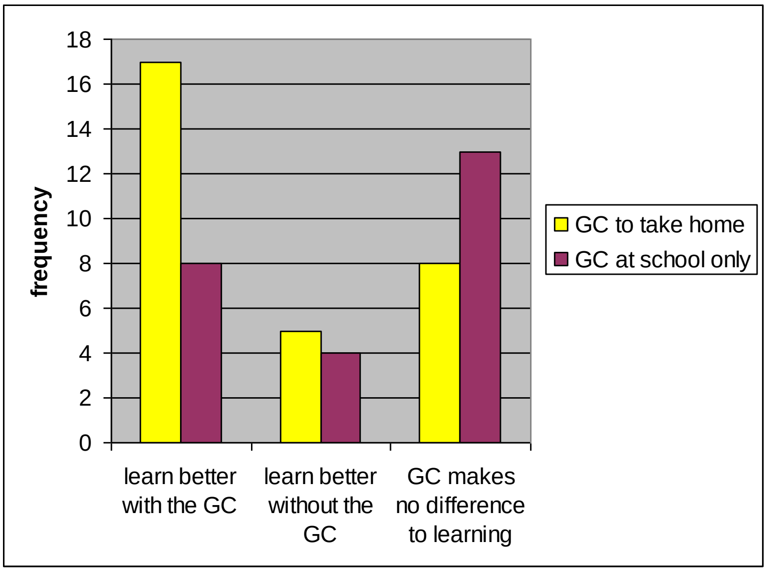
As this bar chart shows, the class who only use the GCs at school seem to find their mathematics lessons more enjoyable and more interesting. However, since this is both with and without the GCs, this finding seems more likely to reflect existing differences between the classes, rather than any impact of the way GC provision is organised. Supporting this conclusion, no statistically significant differences were found between the two classes for the differences in ratings of enjoyment and of interest with and without the GCs (difference between ratings for items 1 and 2; difference between ratings for items 3 and 4).

However, a year later, this situation has changed so that those students with personal ownership were more positive.



December 2008

Learners were also asked whether overall they felt they “learn maths better with or without the GC”. Here there does seem to be some difference between the two classes, as shown below:



Responses to the question, "Overall, do you think you learn maths better with or without the GC?" (June 2008)

The learners with personal ownership of the GCs tended to think that they learned better with the GCs and were less likely to perceive the devices as making no difference to learning. Unfortunately, it is not possible to test this possible association using Chi Square because some assumptions of that test are not fulfilled.

Teacher's perspective on personal ownership

The teacher whose class had personal ownership of the GCs noted both benefits and problems arising from this situation.

'*I'm confident that they are using them considerably at home – I set a homework whereby they were to record 10 questions (given on their calculators) into their exercise books.. The ½ term homework produced some very good results.'*

However, there were also practical issues which needed to be resolved:

'*2 students have forgotten their calculators twice last week, so when they did eventually remember them, I didn't allow these 2 to take them home'*.

This appeared to have the desired effect:

'*The 2 students who forgot their calculators have now had them returned to them and seem to have learned the lesson!*'

This teacher also took advantage of the 'class' set of calculators to work with some of her other classes:

'NAVIGATE program on angles used with Year 11 set 2B…they thoroughly enjoyed the experience…will definitely use this program again'

It is not clear from our evidence whether there are any further practical differences between the two models of ownership. For example, from the teacher's point of view, whether there are differences between classes on the degree of practical support needed when students use the GCs or whether the organisational issues are significant.

Discussion

The evolution of ICT in the mathematics classroom: towards the 'connected classroom'

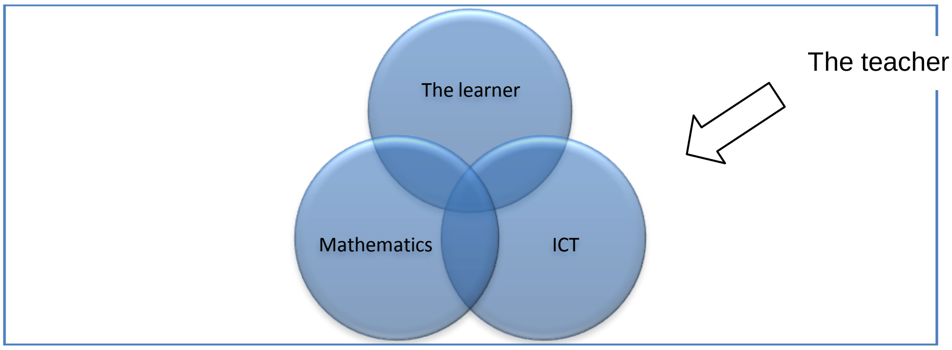


Figure 1: The learner and the PC

Before widespread access to projection technology in mathematics classrooms, most learners' encounters with ICT in the context of mathematics was in a 'computer lab' where they worked on a PC. The teacher was frequently excluded from this encounter (figure 1) and needed to understand the software well in order to mediate the learner's experience. As well as removing the learning from the context of the mathematics classroom, this arrangement tended to privilege the ICT so that it was the ICT which was driving the learning rather than the mathematics.

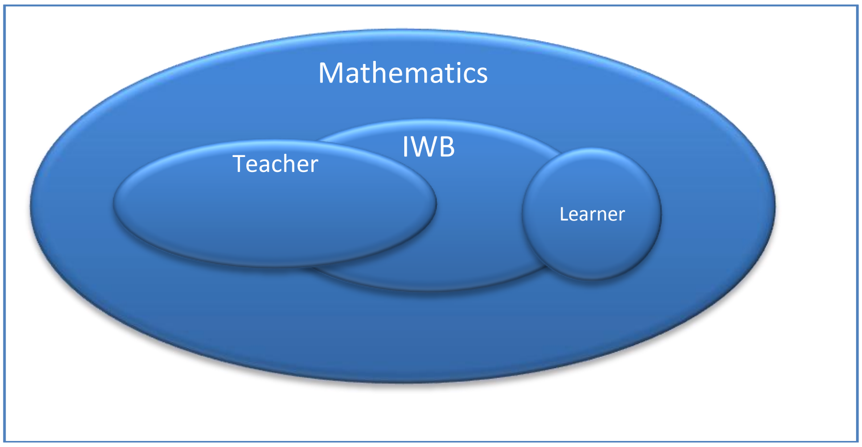


Figure 2: The teacher, the learner and the IWB

The introduction of projection technology, often with the enhancement of the 'interactive whiteboard' (IWB) into the mathematics classroom has placed the ICT in the hands of the teacher. The ICT is generally used as a display, albeit with animation and occasional interaction. Learners relatively rarely use the ICT as a tool for learning in this context. The ICT is usually used to support mathematics teaching and it is the teacher who controls the interaction with the software. (Smith et al, 2006)

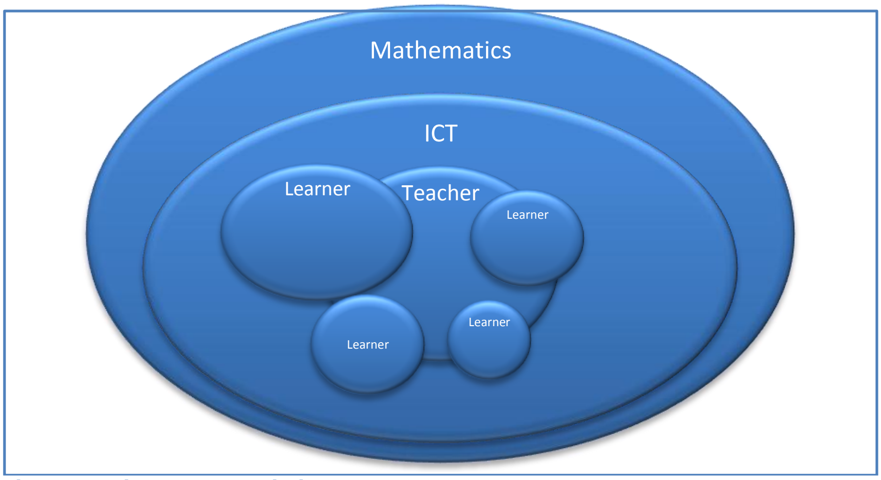


Figure 3: The connected classroom

The combination of handheld personal technology and a networking system combines the advantages of the computer lab and projection technology to create a shared interactive space (digital workspace) in which to do mathematics in the ordinary mathematics classroom. (Hivon et al, 2008)
In this context ICT can be used when the teacher and/or students choose to do so. In addition, students and teachers can share their work or even all participate in the same activity where everyone can see the whole class's contribution.
The connected classroom also crucially supports the assessment and feedback process essential to supporting learners' development.

Provision of ICT in the project school is that most classrooms are equipped with a teacher's pc and projector, usually in combination with an interactive whiteboard. There is also a set of laptops available for use in classrooms, although teachers commented that there were increasing problems associated with these due to their age. Some teachers also use 'voting' technology where students can respond to questions by selecting a response from a handheld 'clicker'. Before the project the department did have a set of GCs, but they were not extensively used by teachers.

Why do learners need personal access to ICT?

In 1995 the National Council for Educational Technology (NCET) convened a study group to report on the benefits for learners of access to ICT to learn mathematics. The group identified six ways in which ICT (at that time) could support learners, they referred to this as an 'entitlement'.

- Learn from feedback
- Observe patterns
- See connections
- Work with dynamic images
- Explore data
- 'Teach' the computer

Perhaps it might also be possible to add a (21st century) item:

- Communicate

This categorisation has been widely elaborated and disseminated, for example through the national strategies, and demonstrates clearly that personal access to ICT is a very important support for students learning mathematics.
There did not appear to be widespread awareness in the project school of these issues.

Portability

In addition to the issue of personal access to ICT the form in which the ICT is available is also important. PCs are essentially designed for office use, not the classroom. Although laptops can provide access to ICT in the ordinary classroom, they pose many demands on the resources and organisation of the classroom teacher even if they are all functioning well. Hence a small form, portable, robust ICT device could be beneficial in the classroom. One report (Hennessey, 1999) identifies the following benefits of portable ICT for education.

- Student empowerment
- Active participation and investigative learning
- Independence and differentiation
- Collaboration
- A tool for mathematical thinking (instrumentation)
- Bridges the gap between school and home

An important issue here is that in this form the ICT is available on demand when either the teacher or student needs it and hence it is the mathematical issues which govern when and how the technology is used, not the converse.

The graphical calculator (GC): a tool for learning mathematics

The GC is a powerful, mature technology developed specifically to support mathematical thinking. A 'vertical', specialised technology rather than a generic 'horizontal' one. (Models offer computation, graphing, solving equations, statistical analysis, simultaneous equations, sequences and series, differentiation and integration, evaluation of functions and complex arithmetic. Some models have computer algebra systems (CASs) and interactive geometry software built in. Certain GCs, like the TI84 used in this project or the Casio 'Classpad' have 'flash ROM' technology, which acts like the hard disk on a PC and provides an extensive, non-volatile memory (in other words, data or programs will not be lost when the RAM is cleared or batteries are removed). This allows the device to store a range of software such as an upgradable operating system, quite sophisticated applications like spreadsheets, and small, specialized software applications like the SMILE programs.

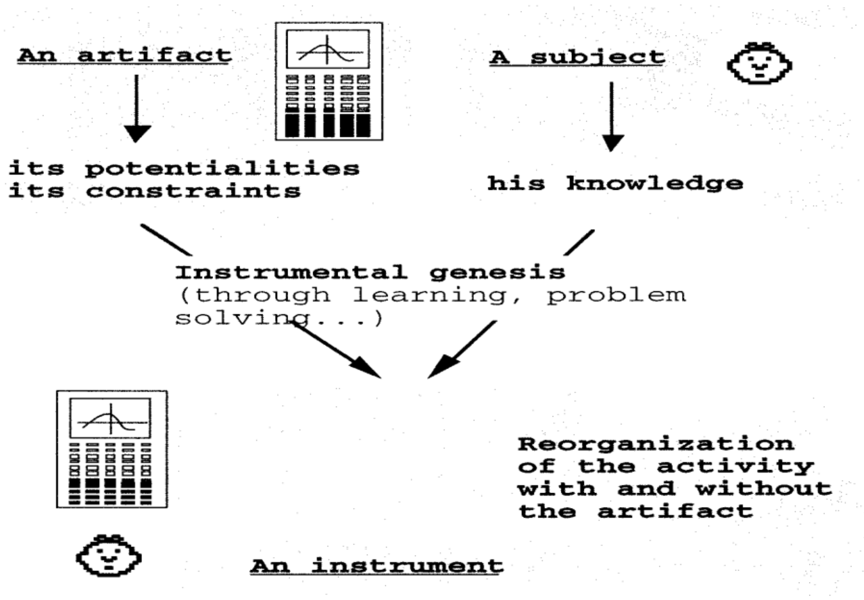
Thus, the functionality of the GC can be extended into the same area as the PC. GCs also have input/output ports and connectors, which allow them to communicate with each other, with computers (and hence with printers and the internet) and with compatible devices such as data-loggers and controllers. Built-in or detachable keyboards are available for some models which allow text to be input directly. There are teachers' versions of most models connecting to a pad of about A4 size with a transparent liquid crystal display which can be placed on an overhead projector and used for whole-class work. Alternatively some manufacturers e.g.: the TI 'Smartview' © offer emulator software so that projection technology can be used for whole class work. Some models e.g. the Casio 'Classpad', have pen-driven interfaces. (Wright, 2004)

The network connections now being developed add a further layer of affordances to this technology, allowing it to be used to support assessment and feedback as well as the creation of a shared interactive mathematical environment in the classroom.

The latest developments in this technology, for example from TI, (the TI-nspire) offers an integrated, windows like environment built around documents which are interactive and designed to offer multiple representations of mathematical objects.

GCs are manufactured by Casio and Sharp in Japan and Hewlett Packard and Texas Instruments in the USA.

Such sophisticated devices demand training and practice to be used fluently as a 'tool for thinking'. There is a research programme, mainly based in France, which is focused on this process called 'Instrumentation'



This theory focuses attention on the complex process involved in learning how to use such artefacts as complex tools to support mathematisation. It is seen as a two-way 'dialectical' process, where in learning how to use the artefact as a tool, the learner also changes their view about its potential for supporting problem solving.
"Instruments emerge through a dialectical interplay between the technical demands of mastering a device and the conceptual work of making that device meaningful in the context of a task." (Artigue, 2002)
This project demonstrated that students and teachers had made some progress along this curve – initially using the GC as a small scale PC which provided easy on-demand access to software 'microworlds' but then broadening their usage to the graphing functionality too.
The addition of a networking functionality to this technology added an extra layer of complexity to the classroom situation. Teachers were then required to 'orchestrate' these emerging 'instruments' and their learners. (Hivon et al, 2008) These demands were unanticipated by the project and hence slow progress was made in exploring this functionality.

Classroom connectivity

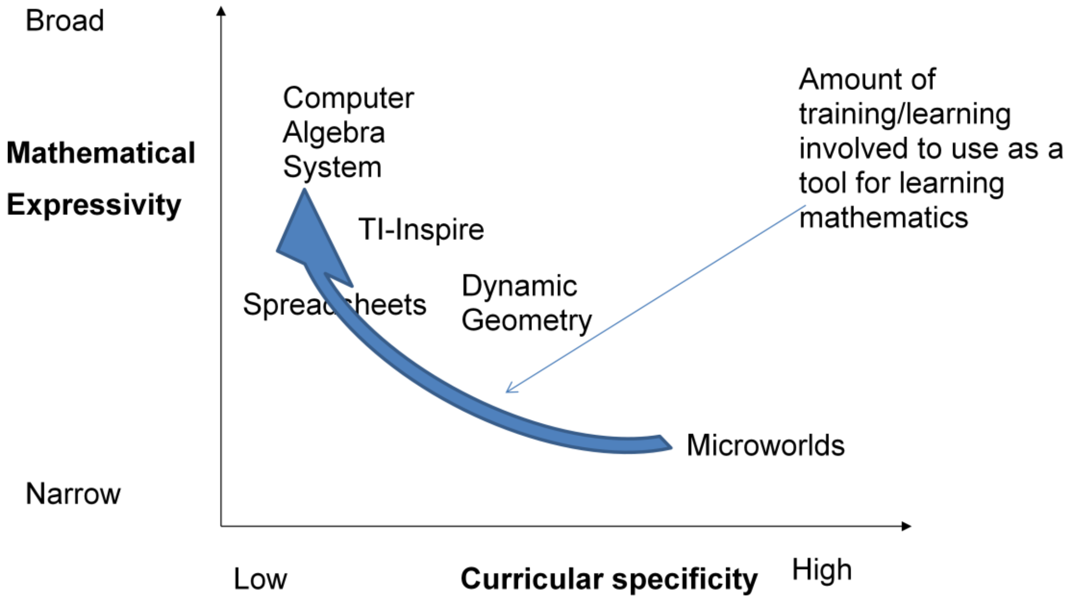
This new generation of classroom based networks has been available in prototype for some time (Davis SM, 2002). Researchers in the US (Roschelle et al, 2003) and France (Hivon et al, 2006) have been investigating their use in the mathematics classroom.
Emerging issues from this research point to some potentially powerful outcomes.

- The affordance of 'ubiquitous' connected access to ICT resources in the 'normal' mathematics classroom to support learning and teaching mathematics.
- The potential for stimulating and supporting a rich variety of assessment and feedback activities
- The emergence of a new type of pedagogy (the French refer to it as 'orchestration' (Hivon et al, 2006)
- A situation in which mathematics is more than content, but where it 'structures social space' (Stroup et al ,2002)

We have observed the emergence of some of these issues in the limited time available for this project. However, the research also indicates that this is a process which takes substantial time and professional development and this has been a limitation of this inquiry.

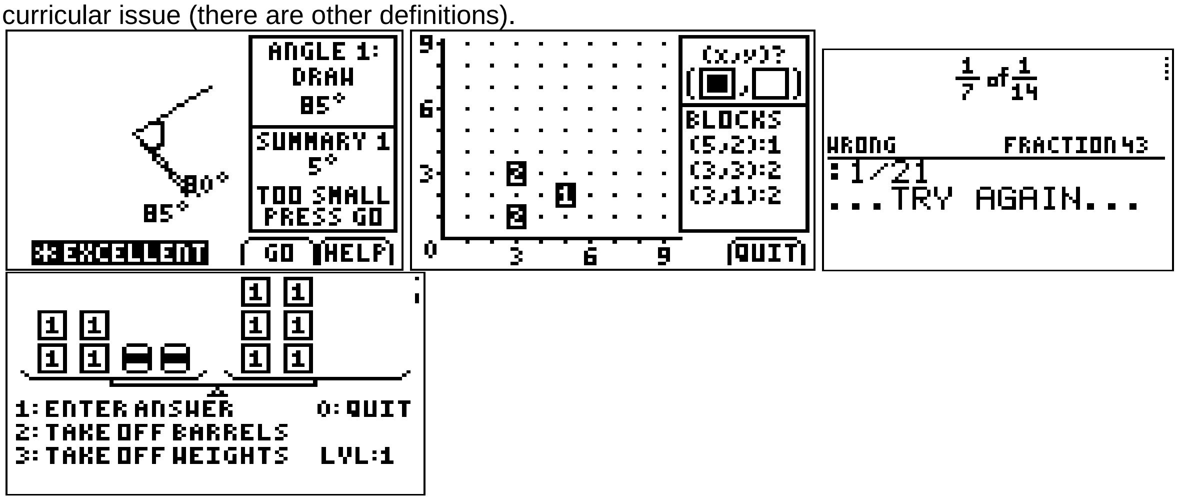
'Microworlds' as a starting point in using GCs

The 'learning curve' to attain fluency with a GC as an 'instrument' can be a lengthy process, but this does not mean that students and teachers must go through this before they can use the GC to support mathematical activities.



All these applications can run on a GC – the ‘microworld’ provides an easy entry point.

We define a ‘microworld’ to be a piece of software specifically designed to focus on a specific curricular issue (there are other definitions).



Screen shots of some ‘microworlds’ available on GCs

These demand relatively little technological understanding on the part of the user, but use the properties of ICT such as speed and interactivity to provoke the user to engage in mathematical thinking. Hence they are easily accessible for students and teachers to use in the mathematics classroom. The combination of the accessibility of these small software programs and the portability of the GC make them immediately useful in the mathematics classroom.
Teachers and students in the project school were able to use an extensive variety of small software programs in their lessons with relatively little training and organisation, compared to a similar facility in a ‘computer lab’.

Professional development

The progress which has been made has rested on the good will, energy and commitment of the teachers involved in the project. Their willingness to take risks and to engage in situations outside their ‘comfort zone’ has allowed us to develop some understanding of the benefits and drawbacks of this technology.

It has already been noted that there is a tension between teachers failing to adopt an innovation because of the extra demands made on them and their integrating the innovation, but it making little impact because teachers' practice does not change.

Cordingley at al. (2003) using meta-analysis techniques identify a number of core features of collaborative CPD which were linked to positive outcomes:

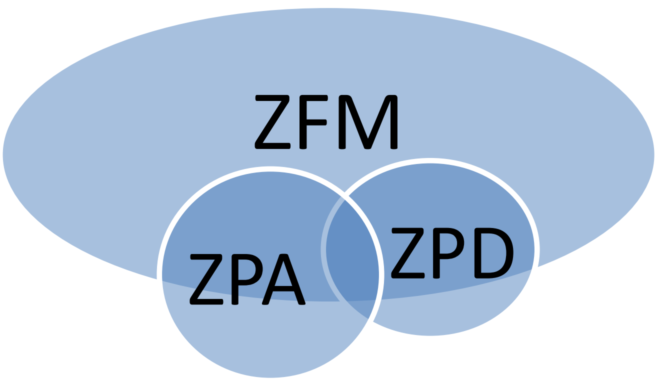
- The use of external expertise linked to school-based activity;
- Observation;
- Feedback (usually based on observation);
- An emphasis on peer support rather than leadership by supervisors;
- Scope for teacher participants to identify their own CPD focus;
- Processes to encourage, extend and structure professional dialogue;
- Processes for sustaining the CPD over time to enable teachers to embed the practices in their own classroom settings.

In a similar vein (Timperley et al, 2007) have identified the characteristics of continuing professional development of teachers that are associated with improved student outcomes, which include:

- Extended time for opportunities to learn (this was necessary but not sufficient)
- Teachers' engagement in learning was more important than initial volunteering;
- Prevailing discourses were challenged;
- Opportunities to participate in a professional learning community were more important than place;
- Active school leadership

Some of these features were present in this project but not always sustained and hence aspects of it lost momentum from time to time. In particular there was not enough time and support available to help the teachers plan for their use of the network and for some aspects of the GC activities. This may have been a factor in the teachers not 'owning' the use of the network to the extent that they used the GCs.

One model of professional development which might be helpful in understanding the factors involved in CPD is Valsiner's zone theory. (Valsiner, 1997; Goos, 2008)



In this model , an extension of Vygotsky's theory, there are three 'zones' which impact on a professional's development.

- ZFM is the zone of freedom of movement – the resources available to the teacher for their learning and development
- ZPD is the zone of proximal development (Vygotsky) – the potential for development and learning within the grasp of the teacher.
- ZPA is the zone of promoted action – those influences on the teacher which may impact on the direction of their learning and development.

Professional development and learning will only occur in the intersection between these three zones – the greater the intersection, the greater the potential for professional development.

In our project there were limitations imposed by the ZFM – in particular the time available, but also, for example, the limitations of the school's network which caused some difficulties in setting up and using the available software. There were also issues where there was not a substantial intersection between the ZPD of the teacher and the ZPA of the project. (Note the potential for a teacher's practice to remain within their 'comfort zone' if the ZPA is not active). For example, in some uses of the network 'activity centre' shared digital workspace and the 'polling' feature of the network not enough preparation and discussion took place to explore and plan some of the uses of this and hence it was not extensively used by the teachers.

The teachers used departmental CPD time to present some of the activities to other members of the department and thus the project has had an impact outside of the teachers involved and several of the department have taken the opportunity to use the equipment and to extend their practice. Hence the trajectory of development has not ceased with the end of this enquiry.

Conclusion

1. Early adoption of technical innovations by 'mainstream' teachers depends on:
    a. A relatively undemanding commitment initially in learning about its functionality,
    b. where the application fits in well to teachers' existing practice
    c. where there is an immediate gain in 'value added' to the learning of the students.
    d. Technical support is readily available to sort out any 'hitches'
    e. BUT note the importance of an 'outside' influence in order for the ZPA to remain active.

2. Planning, both 'large scale' in schemes of work and 'small scale' lesson planning is crucial for the sustained use of the technology. This has implications for the allocation of time for professional development.

3. A sense of ownership by the teachers of the innovation and personal ownership by students of the technology is important in order to sustain the innovation.
4. This use of the GC, as a mature technology which is relatively robust, portable and focused in its use in STEM subjects, demonstrates how technology can be effectively integrated into the 'normal' classroom.

5. The emerging understanding that the affordance of the extra dimension of a connected classroom through wireless networking of handheld technology has the potential to transform the way mathematics is taught and learnt.

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