Factors Influencing Teacher Integration of Graphic Calculators in Teaching Mathematics

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Abtract: Graphic calculators (GC's) are now being more widely used in the learning of school mathematics. However there is still resistance to their use in some quarters, and so it appears that further analysis of the factors acting as possible affordances and constraints to GC use is necessary. This research addressed this issue of the potential affordances and constraints for secondary mathematics teachers using GC's in their year 12 and 13 (age 17/18 years) teaching. Three major areas where such factors are found are: those emanating from the individual teacher themselves; the school mathematics department, and especially the head of department; and the wider school policy and attitudes to technology use. In this study we laid down criteria to identify teachers who could be described as exemplary GC users. We describe and analyse the kinds of use that these teachers are making of the GC in terms of a conceptual/procedural divide, and identify individual, departmental and school factors that could be assisting or preventing technology use. From among these factors key variables that seem to be driving successful implementation of GC use are identified.

1. Background

One of the key factors in the use of graphic calculators (GC's) in the learning of school mathematics (or indeed of tertiary mathematics) is the teacher. In turn, there are many factors that influence a teacher's use of GC's, as with any technology. These include the *affordances* and *constraints* (see below) of the environment they work in (see [1]) and their attitude to, and beliefs about, the mathematics and the technology, as well as their confidence and ability in using it to teach mathematics. These teacher affective variables (such as beliefs and attitudes), their perceptions of the nature of mathematical knowledge and how it should be learned, their mathematical content knowledge, and their *pedagogical content knowledge* (see [2]) all influence their teaching. When we add the potentially subversive element of technology to this mix (see [3]) then the situation may change radically. Teaching mathematics with technology involves the development of *pedagogical technology knowledge* (PTK) (see [4]), or knowing the principles and techniques required to teach mathematics through the technology. This necessitates a new mindset on the part of teachers, a '*shift of mathematical focus'* (see [3]), to a broader perspective of the implications of the technology for the learning of the mathematics.

This PTK partly comprises the teacher's perspective on the technology and partly their familiarity with it. They need to appreciate that technological tools, such as GC's may be employed in teaching in qualitatively different ways, such as for: property investigation; computation; transformation; data collection and analysis; visualizing; and checking (see [5]), and that students may form a variety of different relationships with them (see [6]) depending on teacher direction. This directional emphasis, or *teacher privileging* (see [7]), has been shown to shape student preferences, so that they follow the teacher's lead. A second key aspect of PTK surrounds the transforming of a technological tool into an instrument (see [8]). This engages the teacher in actions and decisions to adapt the tool to a particular mathematical task by considering what it can do and how. This concerns more than just the mechanics of the getting the syntax and semantics of the input/output, the algebraic expectation, and coping with the difficulties of navigating between screens and between menu operations. It means seeing how the technology can mediate between the user and the mathematics. Hence, Guin and Trouche [9] stress the need for instrumentation and conceptualisation to occur concurrently in the classroom, and so teachers need to focus technological activity on specific conceptions.

Gibson [10] has described a theory that presents relationships between agents, in our case teachers, and the environment they seek to interact with. A key feature of this interaction is the presence of *affordances* (attributes of the environment that contribute to the potential for an interaction to occur) and *constraints* (characteristics of the affordance that provide structure and guidance for the interaction, see [11]). In this mix, according to Greeno (see [1], p. 338), "An affordance relates attributes of something in the environment to an interactive activity by an agent who has some ability". In short, affordances speak about the potential for action, while constraints impose the structure for that action. Thus, an example of an affordance, given by Gibson is the provision of mailboxes for posting letters. In a technology classroom setting, the presence of technology such as the GC is an affordance, with student or teacher instrumentation, time available to use the technology and the content of curriculum as examples of constraints. The role of the teacher in this theoretical model, according to Kennewell [11], is to orchestrate the affordances and constraints so that learning takes place. Other researchers have used different words to describe the nature of constraints with regard to technology use in mathematics learning. For example, Forgasz [12] talks about encouraging and inhibiting factors, while Thomas [13] uses the terminology of obstacles to technology use. However, there is a difference between a constraint, which implies the presence of an affordance, and a factor that inhibits the presence of an entity with its potential for affordance, in the environment. We will reserve the use of the term obstacle for this latter idea, namely something that prevents the presence of an affordance-producing entity in the classroom situation. In this paper we consider the implementation of GC technology in mathematics teaching by three teachers. We describe their use of GC's in the classroom, their perspective of them, and seek to identify and analyse the relative importance of the affordances and constraints in operation.

2. Method

This research comprised an in-depth case study of ten secondary school teachers using GC's in their teaching in Auckland, New Zealand during 2005. In particular the work of three of them is the subject of this paper, chosen because of their comparatively positive work with the GC's, and to cover a wide range of obstacles and constraints. These three teachers, who we shall call D, M and S, volunteered to participate in the study. Teacher D was a relatively new teacher, with 4 years' experience, who had made only a little use of GC's in teaching, and who taught in a low socio-economic school (decile 2). Teacher M has 9 years' teaching experience, had made some use of technology in teaching, and taught in a middle socio-economic school (decile 5). Teacher S is a deputy head of department (HOD) with 20 years' teaching experience, including a number of years implementing technology in her teaching, and she works in a high socio-economic school (decile 10). The first-named researcher carried out the fieldwork and had an initial meeting with each of the teachers before any data collection took place. At this initial meeting the topics to be taught, the time-lines and the technology to be used were discussed, and further, more detailed discussion took place by email. At this initial meeting the participating teachers were given a Likert-style attitude test (see Figure 2.1) with five subscales, comprising attitude to: mathematics, technology in general, personal learning, technology and GC in learning mathematics. The Cronbach's Alpha reliability coefficient for this scale was calculated at 0.898, making it an internally consistent reliable scale. They were also given a diary and encouraged to complete it for all their GC lessons, including their lesson aims and expected outcomes, teaching method, classroom organization, details of GC use, and their reflection on student learning. We made a total of 8 lesson observations; three for year 13 (aged 18 years) for teacher D and two for teachers M and S, and one year 12 lesson for teacher S. After these observations were completed the teachers were interviewed for about 40 minutes, and these were tape-recorded and later transcribed for analysis.

Mathematics Attitude Questionnaire

Name: ____________________________ **School:** ____________________________

Levels of Teaching (Circle): Y7 Y8 Y9 Y10 Y11 Y12 Y13 Years of Teaching: __________

Please circle the numbers on the right below corresponding to which of the following indicates your level of agreement with each statement.

5 – I STRONGLY AGREE (SA) with the statement 4 – I AGREE (A) with the statement 3 – NEUTRAL (N)
2 – I DISAGREE (D) with the statement 1 – I STRONGLY DISAGREE (SD) with the statement

	SA	A	N	D	SD
1. More interesting mathematics problems can be done when students have access to technology.	5	4	3	2	1
2. Students understand mathematics better if they solve problems using paper and pencil.	5	4	3	2	1
3. I have lots of ideas about how I can make use of technology in mathematics.	5	4	3	2	1
4. Students should not be allowed to use technology during mathematics tests or examinations.	5	4	3	2	1
5. I think technology is a very important tool for learning mathematics.	5	4	3	2	1
6. Technology can be used as a tool to solve problems students could not solve without it.	5	4	3	2	1
7. Technology is only a tool for doing calculations more quickly.	5	4	3	2	1
8. Technology can make mathematics more fun.	5	4	3	2	1
9. Students should use technology less often in mathematics.	5	4	3	2	1
10. Using technology will cause students to lose basic computational skills.	5	4	3	2	1
11. I want to improve my ability to teach with technology.	5	4	3	2	1
12. Students rely on technology too much when solving problems.	5	4	3	2	1
13. Technology should only be used to check work once the problem has been worked out on paper.	5	4	3	2	1
14. Mathematics students need to know how to use technology.	5	4	3	2	1
15. Students should not be allowed to use technology until they have mastered the idea or the method.	5	4	3	2	1
16. Mathematics is easier if technology is used to solve problems.	5	4	3	2	1
17. Learning how to use technology is difficult for me.	5	4	3	2	1
18. Using technology makes students better problem solvers.	5	4	3	2	1
19. I lack the confidence to use technology to solve mathematical problems.	5	4	3	2	1
20. Learning mathematics is mostly memorising a set of facts and rules.	5	4	3	2	1
21. When doing mathematics it is more important to know how to do a process than to understand why it works.	5	4	3	2	1
22. Learning mathematics means exploring problems to discover patterns and make generalisations.	5	4	3	2	1
23. Students would be better motivated in maths if they could use a graphic calculator.	5	4	3	2	1
24. Using a graphic calculator removes some learning opportunities for students.	5	4	3	2	1
25. Students would understand maths better if they had a graphic calculator.	5	4	3	2	1
26. Using a graphic calculator would make the management of data easier.	5	4	3	2	1
27. Students would be more confident in maths if they had a graphic calculator.	5	4	3	2	1
28. Since students can use a graphic calculator, they do not need to learn to draw graphs by hand.	5	4	3	2	1
29. I feel that computer algebra system calculators should be allowed in mathematics tests and examinations.	5	4	3	2	1
30. Using a graphic calculator to solve statistics makes the problems easier to understand.	5	4	3	2	1

Figure 2.1 The Attitude Questionnaire

3. Results and Discussion

In his research study, Becker [14] developed criteria for considering whether or not teachers were exemplary in their use of computers. While we did not choose to apply his criteria, or to label our teachers as exemplary, his ideas did encourage us to look at the ten teachers for those who demonstrated their use of technology before the present study as good. The three teachers we chose were making use of GC's on a fairly regular basis, viewed their use in some way as central to their teaching and seemed to encourage students to use them for approaching conceptual ideas and not just procedures. In view of this background these three teachers were selected for further investigation in terms of how they were using the GC in their teaching and the key factors driving them to do so. A focus of this study was not only to see how the teachers were using the GC but to analyse the reasons why they used them, and the pertinent affordances, constraints and obstacles relevant to their situations.

3.1 The teachers' use of GC's

Teacher S works in a high socio-economic school (decile 10). She has 20 years' teaching experience and has been using GC's for three years. We made 3 visits to observe her classroom. The first involved year 12 students (age 17 years) studying probability simulations in statistics, and the second and third observations were of year 13 students (age 18 years) working on calculus, stationary points and trigonometry. In each lesson the teacher and all her students had access to TI-83+ calculators. While in her interview she stressed the value of the technology for covering more ground "…the number of things that they can do in any one lesson is far greater so it's better than drawing. Usually it takes you all lesson to draw three (graphs). You can draw ten with a graphics calculator and they can really understand it for themselves…", she mentions student understanding, which was a focus for her. She also stressed the visual benefits of the GC's in this:

> …it gives the students a visual interpretation, a hands-on approach; it's not all just writing, they can see things happening, particularly with the probability simulations yesterday. I felt they had a much better comprehension of what was actually happening so they got a visual picture but also every time they did it …they could see it happening differently every time.

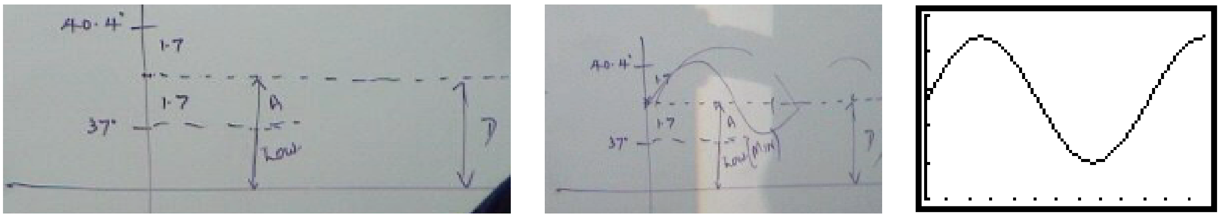
These two ideas converge in her mind to give students the ability to generalise "I think it's the amount of visual information they can get, and the amount of examples they can get through, so they really feel they understood it because they've seen so many that they can actually accept and they can generalize for themselves and it gives a better understanding." Rather than focussing simply on getting her students to perform procedures she talked about how "they had a much better concept of what was actually happening". She does not put the emphasis in class on the instrumentation of the GC, instead "Basically if I'm organized I'll make a worksheet with the 5 keys we'll use that day or put the 5 keys we'll use on the blackboard, go over those and just spend 5 minutes on what we're going to day for the day". This approach was confirmed by the observation of her second lesson, on concavity. Her teaching was focused on using the technology to improve conceptual understanding, with an emphasis on visual representations of functions. She explained the concept of concavity on the whiteboard (see Figure 3.1), followed by turning point, stationary point, local maximum and minimum points. Teacher S also gave the definition of a point of inflection, showing that it may have a non-zero gradient. The students then worked on the function $y = x^4 - 2x^3$, to find its key features, such as concavity, being encouraged to work by-hand and on the GC (with, eg, [2^{nd}] [Trace] to find turning points) in parallel.

The lesson's concepts The point of inflection

Figure 3.1 Teacher S's Conceptual Emphasis in Differentiation

In her third lesson she considered how the GC could help her students understand and recognise key concepts of functions $y = A\sin B(x+C) + D$, such as amplitude, period, maximum and minimum values. This led to a question using trig functions to model temperature:

> A patient in the hospital had an illness in which his temperature (in degrees census) varied front it low of 37° to a high of 40.4°. The length of time between successive highs is 16 days. Determine the formula for the temperature, T, of the patient at time in days since the beginning of the illness. Assume that the function describing the temperature can be modelled with a sine function, with no phase shift.



a) Preliminary data b) Beginning the curve c) Using the GC

Figure 3.2 Teacher S Integrates the GC in Modelling

In this she got the students to work by-hand on the conceptual structure of the problem, and then integrated the GC into the solution process. The students found A as 1.7 from (40.4–37)/2 (Figure 3.2a), D as 38.7 (37+1.7), and B as $\frac{\pi}{8}$ from B=2π/period, to give $y = 1.7\sin\left(\frac{\pi x}{8}\right) + 38.7$.

Teacher M works in a medium socio-economic level school (decile 5). She has 9 years' teaching experience and has also been using GC's for 3 years. We made 2 observation visits to her classroom, both involving year 13 students (age 18 years) studying firstly trigonometric graphs and their transformations, and then the solution of trigonometric equations. The school allowed GC use in examinations and encouraged students to buy their own calculator, but the financial situation at the school was not considered good enough to support technology; according to the head of the department "the budget doesn't allow for it." Hence the mathematics department did not have a class set of GC's or a viewscreen, so she had an obstacle to overcome when she wanted to demonstrate working with a GC. When we visited teacher M's class only 7 of the 14 students had their own scientific or graphic calculator, and so the students shared with each other or worked without a calculator. Thus she worked under the constraint that the calculators were not all the same, and so she had to explain how to work with each model. Teacher M used a CASIO fx-9750G GC and an overhead projector (OHP) on which she wrote to demonstrate and explain key points.

In her interview teacher M spoke about the visual value of the GC, how "when they have a graphics calculator, it's very useful for them to see how the graphs… what the graphs look like, and you can change numbers". She also mentioned the time-saving aspects of its use "It's much faster, quicker and easier". However, she also thinks of the conceptual value of the GC in helping students make connections.

> I think it's important for them to understand concepts in mathematics and there's got to be a balance between the skills they do and the word problems…Basically we want them to be able to see what the concept is, and instead of sketching it every time… so if you want them to check for 'y=3cos(4x)', they have independently seen what is happening to 'cos (4x)' and what happens when they [do] '2cos(x)', and they can put the two together and get it from the graphics calculator quicker and they can see the changes much faster.

On the subject of GC instrumentation teacher M does not put a lot of emphasis on getting students to think about what buttons to press, etc. She says that once they have the basics students are quick to pick up what they need in each lesson: "I don't put it all up at the beginning of the lesson or they'll get confused with it. I do it as and when I feel it's necessary. But generally, switching it on, feeling the menu and how to use the cursor, most of the students know. That's why I put the instructions up and most of them caught on to it very quickly". Her emphasis on conceptual understanding was seen in an interview comment "I think it's important for them to understand concepts in mathematics and there's got to be a balance between the skills they do and the word problems they work out."

In her first lesson with the year 13 students (age 18 years) teacher M used the GC to allow students to investigate graphs of the form $y = A\sin B(x + C) + D$, etc. First she concentrated on the effect of a single parameter, using $y = A\sin x$, with A=2, 3 and 0.5, and asking what these numbers signified, and then moved on to graphs of the form y=cos(Bx), with B=2 and 3. Students were encouraged to work together, "Discuss with the person sitting next to you the effect of y=sin(Bx).", and she also got students to come out and sketch graphs on the white board. In each case she tried to get students to focus on the concepts of domain, range, period, amplitude and frequency, asking questions such as "What does the number 2 signify?". She explained the conceptual approach, and the role of the GC this way:

> Instead of just sketching 'y = cos (2x)' and then after it doing 'y = cos (3x)', they've got to see the connection. If they see... keep changing the variables, and they see the effect of that, that's conceptual understanding and that's what we should be getting at and the graphics calculator is really useful for that."

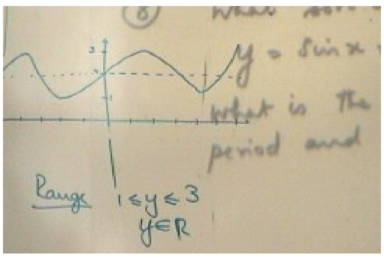
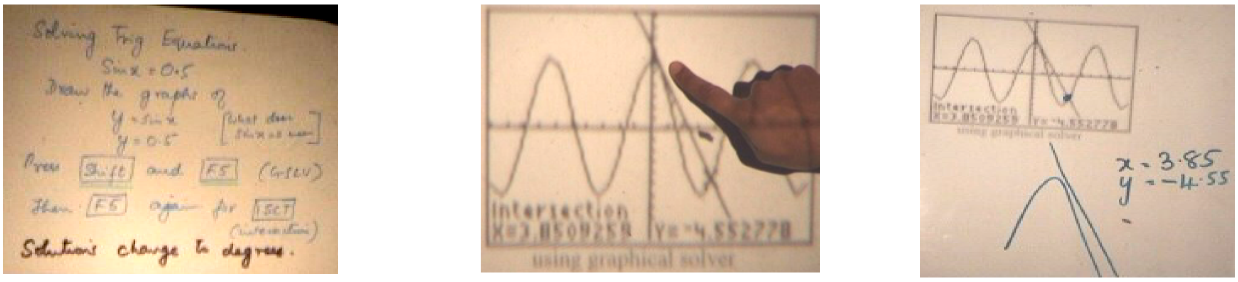


Figure 3.3 Teacher M Stresses the Concepts of Range and Period for y=sin$x$ + 2

Moving on she focused on the concept of translation, asking "What sort of translation is y=sin$x$+2? What is [sic] the domain, range and period? What does [the] graph look like?" Figure 3.3 shows her use of some of the key ideas on the overhead projector. In the second lesson was spent solving equations such as sin$x$ = 0.5. To do this she got the students to draw the graphs of y=sin$x$ and y=0.5 on the GC (see Figure 3.4a) and consider their intersection. Afterwards she used this same concept to get them to solve 7–3x = 6cos$x$. Since she did not want her students to be procedural users of the GC, but to think about the mathematics, she used this example as an opportunity to get them to look through what they saw on the screen. She pointed to the apparent intersection of the two graphs near the y-axis (see Figure 3.4b) and asked the students to use the GC to zoom in on that area. They could then see that the line does not actually intersect the curve (see Figure 3.3c) and that was why there was no solution given by the GC, instead "When you press [G-Solve], it always give you first intersection from left to right, then x = 3.85, y = –4.55."



a) y=sin$x$ and y=0.5 for sin$x$ = 0.5 b) y=7–3x and y=6cos$x$ for 7–3x = 6cos$x$ c) Zooming in

Figure 3.4 Teacher M Shows that Trig Equations Can Be Solved with Intersecting Graphs

Teacher D works in a low socio-economic level school (decile 2). He is less experienced than the other two, with 4 years' teaching, was new to using GC's in his teaching and had not attended any GC professional development course. As with teacher M, the school allowed GC use in examinations and encouraged students to buy them, but the majority of the students could not afford one. However, the school was trying to support technology use so the mathematics department had purchased one class set of CASIO fx-9750G calculators and had one classroom with a computer set up for Powerpoint use. Teacher D commented on this constraint that "Very few of the students can afford their own graphics calculator therefore, the only chance they get to practise with them is in the lesson when we hand them out and draw them back again, so they don't get the familiarity …they haven't had the practice in using the technology." We made 3 observations of his classroom. All three lessons involved year 13 students (age 18 years) using the class set of GC'S, one studying the binomial distribution in statistics, and the others the use of power and exponential functions in statistical modelling. Once again teacher D had to work around the obstacles of the lack of an overhead projector and a viewscreen to project his calculator screen. He managed this by using the affordance of a poster of the GC to show students the right key presses, but clearly a poster has constraints, such as not being able to show the result of the key presses.

In his interview teacher D showed that he did not want students simply to use the GC in a procedural manner, but saw the value of an inter-representational approach. The graphical side of the GC was important to him since "it can also provide a visual help to understanding the overall idea.", and he talked about how "students have come to me and said, 'I now understand what you're saying', by having a little presentation of the graph." He also confirmed his desire for a non-procedural approach, saying that his "prime aim would be for them to understand the method and be able to apply it rather than to arrive at the right answer." Actually, his first lesson was rather procedural, using the computing power of the GC to calculate p(x=6)=${}^{9}C_{6}\,0.4^{6}(1–0.4)^{3}$, and finding other probabilities, p($x \geq k$) or p($x \leq k$). It appeared from his interview that the purpose of this lesson was revision, since "Basically the type that they're going to get in the exam." However, for the second lesson on power and exponential functions he tried to integrate the GC into thinking. He gave students the function y=2e$^{-0.45x}$, asking them to sketch the graph for x values from 0 to 3, by completing a table he gave them (see Figure 3.5a) and then plotting the function. Students completed the table by putting x=0, 0.5, 1, 2, 3 into the function $y = 2e^{-0.45x}$ on their GC and then plotting by hand (Figure 3.5b). He used this method rather than getting the GC to draw the final graph so that the students could see how the graph was constructed.

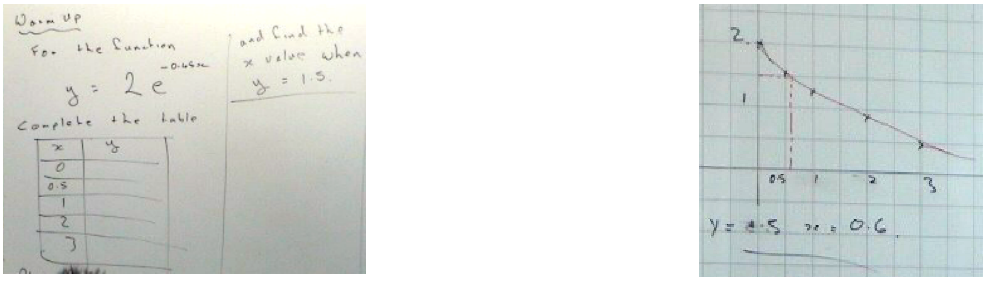


Figure 3.5 Teacher D Integrates the GC into Graph Plotting

A similar process was then followed for graphs of the form $y = x^k$, for k=–2, 1.5 and –0.5. Finally a problem involving the volume of water in a lake at time t, with the function $V = 1275t^{-0.72}$, was considered. Here the function was drawn using the GC. Teacher D asked the students "At what point does the amount of water in the lake drop below 200m^3? When y=200, what is x-value? Use [Trace] key, approach to y=200, you can find the x-value." (variables had been changed on the GC). Here the students had a choice of method. They could either use [G-solve], which gave them the x-value directly, or the [Trace] key on the GC; they preferred the former. This work led into the third lesson on using power and exponential functions to model two variable regression.

3.2 Factors influencing the teachers

An analysis of possible affordances for the action of teaching with technology led us to consider a number of domains where the affordances arise. These include the school's physical infrastructure, the school's personnel structure and relationships, and the technology itself. Hence, when considering the obstacles and constraints that might be influencing the teachers' use of GC's (and other technology) we decided to group them into three sections, departmental, school, and added personal teacher factors. Table 3.1 lists some of these obstacles and constraints.

Table 3.1 Constraints on the Teachers

Teacher	Department	School	Teacher
S	Strong HOD support for GC's	Experience of GC use	Experienced GC user
	Other supportive teachers	Strong support for GC's	Strong GC confidence
M	Weak HOD support for GC's	New to GC use	New GC user
	No supportive teachers	Weak support for GC's	Weak GC confidence
D	Weak HOD support for GC's	New to GC use	New GC user
	No supportive teachers	Strong support for GC's	Weak GC confidence

Although two of the teachers (M and D) had relatively weak personal instrumentation of the GC they did not allow this to prevent them from trying to introduce it in a conceptual way. One might expect that a supportive school and department would be necessary factors for a teacher to introduce technology into teaching, but we see from Table 3.1 that two of the teachers did not have this background. In fact only teacher S had the profile that one might consider ideal for a successful outcome. She also was more experienced with GC's and was the only teacher to have had professional development with them, and her lessons showed this. This led us to think that other factors might be at least as important in promoting teacher use of GC's. Prior to the start of our observations, and therefore measuring the existing situation, we had given the teachers an attitude test with five subscales, comprising their attitude to: mathematics, technology in general, personal learning, use of the GC in learning mathematics. In Table 3.2 we see a set of summary means for each of the subscales for all ten teachers in our wider study, all of whom were teaching mathematics with technology.

Table 3.2 Means for the Five Attitude Test Subscales for the Teachers

	Attitude to Maths	Attitude to Technology	Personal Learning	Technology in Learning Maths	GC's in Learning Maths
10 Teachers	3.80	3.85	4.02	4.51	3.89

All ten teachers were positive to technology use, and especially its use in teaching mathematics. We note that the means of teachers D, M, and S were not significantly different from the others in the five subscales. However, in their attitude to personal learning they were slightly more positive that the others (mean=4.17), although not significantly so. In this subscale one question in particular is noteworthy. In Q11 'I want to improve my ability to teach with technology' the ten averaged 4.51 out of 5, strong agreement, with teachers D, M and S averaging 4.67 (4.43 for the others).

4. Conclusion

Although mathematics teachers often claim to be supportive of the use of technology in their teaching (see [12], [13]), the degree and type of use in the classroom often does not correlate with this (see [15]). Research into the uptake and implementation of technology in mathematics teaching has identified a range of factors influencing it. Goos [16] lists some of these as: skill and previous experience in using technology; time and opportunities to learn (pre-service education, guidance during practicum and beginning teaching, professional development); access to hardware (computers and calculators), software, and computer laboratories; availability of appropriate teaching materials; technical support; support from colleagues and school administration; curriculum and assessment requirements and how teachers interpret these for students perceived to have different mathematical abilities; knowledge of how to integrate technology into mathematics teaching; and beliefs about mathematics and how it is learned. Forgasz [12] agrees, with her computer survey listing access to computers and/or computer laboratories as the most prevalent inhibiting factor (constraint), with lack of professional development and technical problems, including lack of technical support next. Thomas's [13] survey of computer use in all New Zealand secondary schools found that teachers make similar statements, citing availability of computers as the major issue, followed by a lack of software, training and confidence. The first two may be described as obstacles, while the last two are constraints.

Some literature points out the influence of teacher beliefs and attitudes on their teaching practice. In her study, Forgasz [12] found that teacher confidence, experience, skills or enjoyment of computers was the third highest factor encouraging computer use. While we cannot make any definite conclusions from our small-scale study it is interesting to note that teachers who have few school resources, are not well supported by their head of department, and who do not have strong personal GC skills can do quite well in implementing GC use. Our attitude questionnaire seems to point to the fact that the teacher's personal attitudes and beliefs, if strong enough, will override these other negative constraints and obstacles. In particular, our results suggest that a strong belief in the value of technology in learning mathematics coupled with a strong willingness to be open to personal learning could be crucial factors. Further research will be necessary to test this hypothesis.

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