Investigating the Appropriation of Graphical Calculators by Mathematics Students

by

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The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others.

Dedication

Jes,

Always

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A huge debt of gratitude must be paid to my supervisor, **Dr John Monaghan** who has steered me through the whole process of an Ed.D, offered excellent advice, was always willing to discuss the latest draft and who re-motivated me during the numerous times of doubt. I couldn't have asked for a kinder, more generous and more enthusiastic supervisor. Thank you John.

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Abstract

The primary aim of this research is to investigate students' use of graphical calculators for high school mathematics. I see appropriation of the technology to be central to this and therefore I discuss the term appropriation and outline the definition of appropriation I will adhere to.

In particular I followed six students through the academic year September 2003 to July 2004 with a view to establishing how, why and when they used their graphical calculators and what benefits they gained from its use. I selected the two schools from where the students came and the students volunteered to take part in my project.

My research is broadly socio-cultural as I collected data not only from the students but also about the context in which the students learn. I used a case study approach, focussing on a small number of cases – a case being a student-with-a-GC-in-school. Overall I adopted a naturalistic paradigm for my study and collected qualitative data about the 'natural setting' – the classrooms and schools – and made every attempt to minimise the disruption to the students during their daily routines.

The data was collected through a variety of methods – interviews, observations, journals and key-stroke data from the students' graphical calculators. The key-stroke data are central to my work. The key-stroke capture software used provides an exact record of a student's use of the graphical calculator. This method of collecting data is not widely used or known and I have dedicated a chapter to outline its main features and make a critical analysis of it as a data collection tool.

I see appropriation as a central issue to students using a graphical calculator and as such I reflect on the evidence with this at the forefront. I report on what are the signs that a student has appropriated their graphical calculator and what are the barriers to appropriation.

I found that the six students appropriated their GC to varying degrees. The extent of their appropriation was influenced by a variety of factors including the tension between the old tool and the new tool, the teacher, the institution, the curriculum and personal aspirations. I examine these factors in detail and examine the stages of appropriation of each student.

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Chapter 1 – Introduction

Within this chapter I will relate where my interest in technology and mathematics education came from and also outline how I arrived at the focus for my thesis. I briefly describe what I perceive as appropriation. I conclude this chapter by summarising the contents of the thesis.

1.1 Personal and Professional Background

My interest in using Information and Communications Technology (ICT) to teach A Level Mathematics stems from my own teaching experiences and the professional development courses I have followed.

I taught Mathematics and ICT for eight years within two further education (FE) colleges in the north of England. I taught a variety of students, aged 16 and above from many different social and economic backgrounds and at many different levels and abilities. The courses I taught on were Foundation and Intermediate Levels at GCSE Mathematics; Foundation and Intermediate Levels for Application of Number Key Skills for GNVQ; AS and A2 Level Pure Mathematics; Mathematics modules for BTEC National Diploma in Science and HNC Mechanical Engineering courses. I also taught ICT modules for a range of other courses – Foundation and Intermediate Level ICT Key Skills for GNVQ; ICT module for BTEC National Diploma in Sports Science and in Public Services.

Teaching both Mathematics and ICT within the same institutions enabled me to consider the link between the two subjects and identify the areas of overlap and the ways in which ICT could potentially enhance my teaching of mathematics. During my eight years of teaching I used graphical calculators (GC) and Omnigraph with A Level Mathematics classes. I used these forms of ICT to help teach my AS Level Mathematics students an introduction to calculus and graph transformations. I developed computer-based worksheets to support my teaching and included notes, diagrams and exercises for the students to work through in their own time.

The lessons were received by the students in various ways – ranging from total apathy to complete involvement, and there always seemed to be the complete range of responses in every class. Comparing my approach to teaching these topics with my colleagues I noticed that not every teacher was using ICT to the same extent. While they were encouraged at every level to integrate ICT into their teaching, this integration was rarely achieved. I became very intrigued with this situation and wanted to investigate it further.

While at Huddersfield Technical College (HTC) I achieved my Teachers' Certificate in Information Technology in FE. This year long course was designed to teach participants the rudiments of word processors, spreadsheets, drawing packages and databases. I used this opportunity to develop a bank of resources to help me teach ICT to the different courses I was teaching. Throughout this year I constantly thought about how I could include ICT into my A Level Pure Mathematics teaching and began developing resources for this course.

To develop my skills as a teacher further, I embarked on a Masters degree in Education. For this course I studied four modules and wrote a critical study. The modules I studied were:

- Learning and the New Technologies
- Assessing Mathematics
- Trends in Research in Mathematics Education
- Learning Mathematics

My critical study focused on teachers' use of ICT to teach A Level Mathematics and which factors have an impact on the use of ICT. I conducted a small research project to determine the frequency of use of ICT within a group of mathematics teachers. I interviewed all of the teachers in my college who taught A Level Mathematics. The interviews had a number of specific questions but all started with an opportunity for the teachers to raise issues unprompted by me. The teachers I interviewed said that they perceived a need to use ICT and that they realised the benefits it could bring. It also became apparent that they felt under some, if not a great deal of pressure to include ICT in their A Level Mathematics sessions. But despite this, ICT was not being used to the extent the teachers themselves felt was apposite. I wanted to understand the reasons for the low level of use. I found there were many barriers to the teachers' use and acceptance of ICT. The main three barriers were confidence, time constraints and support (financial, technical, resources and staff development).

The completed study left me with many questions about the students' perspective: how they respond to ICT; under what circumstances they benefit from using ICT; how does ICT affect their understanding. This is the area that I chose to investigate further and take as the main focus for my doctoral thesis.

1.2 Background to my Study

There has been substantial research into ICT within mathematics education in secondary schools and this has resulted in a proliferation of writing about this area. The authors and researchers all tend to have different interests and therefore take a different focus with their projects – the classroom environment, the teacher, the technology, the student or a combination of these. My doctoral study examines the use of ICT by students within AS Level Mathematics programmes and asks if appropriation of a technological artefact could have an impact on a student's mathematical understanding.

Schools and teachers have long been under pressure to integrate ICT into the classroom[1]. There have been many Government initiatives to encourage this and enable all children of school age

[1] The New Opportunities Fund (www.nof.org.uk) provides ICT training to enhance teaching across all subjects by improving, and thereby, increasing, the use of ICT in the classroom.

to have access to ICT during their time at school[2]. While all school subjects have been included in this mandate, the focus on mathematics has been particularly keen. This has been supported by the examination body Qualifications and Curriculum Authority[3], who have allowed GCs to be used within A Level Mathematics module examinations. In their AS and A level specifications in Mathematics (dated June 1999) they state that within these programs students should be encouraged to:

> *"...acquire the skills needed to use technology such as calculators and computers effectively, recognise when such use may be inappropriate and be aware of limitations..."* (para. 2.1 h)

However GCs are not permitted for all the modules and their use is not compulsory in those modules where they are permitted. It is intended that students who do not use graphics calculators will not be disadvantaged.

There have been many different types of software and hardware developed to enable integration of ICT into mathematics classrooms to take place:

- generic mathematics software e.g. spreadsheets;
- specific mathematics software
  - graph plotters – graphics calculators (GCs), Omnigraph, Autograph, ...
  - geometry systems – Cabri, Sketchpad, ...
  - algebra systems – hand-held computer algebra systems (CAS), Derive, ...

The technology, for the most part, is in place within the schools, but complete integration is rarely achieved. Complete integration would mean ICT being used to teach, learn and problem-solve on daily basis. The lack of integration can be attributed to a myriad of factors (Sheryn, 2002):

- Teacher: confidence, time, training, attitude, previous learning experience, previous teaching experience
- Student: confidence, training, attitude, previous learning experience
- Technology: amount of software and hardware support available

Teachers have different opinions as how best to integrate ICT into their A Level Mathematics courses (Sheryn, 2002). In most instances ICT is used to support traditional techniques – students learn mathematics using paper and pencil with ICT being used to consolidate this work (Herwaarden and Gielen, 2002). Some researchers and teachers do take a different stance – as ICT is a relatively new educational tool, new teaching strategies should be adopted and curricula should be adapted to take into account the new instrument (Papert, 1980). Students can use ICT to investigate specific areas of interest, raise their own questions and develop their own understanding of topics.

Different teachers with the same teaching scheme who use the same type of ICT to teach a topic may in fact use it in different ways (Lins, 2001). Teachers will make their own decisions about

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[2] For further information see British Educational Communications and Technology Agency (www.becta.org.uk)

[3] For further information see www.qca.org.uk

how to incorporate it within their lessons and focus on different aspects of the work (Kendal and Stacey, 2001). Different groups of students will achieve in different ways and develop differing approaches to the problems being solved. Kendal and Stacey found that

> "*Students of the teacher who privileged conceptual understanding and student construction of meaning were more able to interpret derivatives. Students of the teacher who privileged performance of routines made better use of the CAS for solving routine problems.*" (ibid. p.143)

Whichever viewpoint is taken, the context within which the ICT is introduced is vital for ensuring that the students are not alienated from using the technology. There are some instances where ICT is being used for the sake of it and students' interest is not being stimulated (Arcavi and Hadas, 2000).

Students of differing abilities can be introduced to the use of ICT. Their speed or skill at mastering the technology is not an indication of their innate ability because generally there is a long way to go from the introduction of ICT to complete mastery. Students are not expected to understand and use every function of the tool but it is anticipated that they will develop a level of understanding and know-how that will assist them in their problem-solving and investigations. When a student has used the technology sufficiently it is possible they will master it and hopefully, eventually appropriate it, i.e. they can add it to their bank of problem-solving instruments that can be called on and used when necessary. Using the tool, problem-solving with it and beginning to understand its potential and constraints may encourage students to consider it an 'instrument' to help them with their mathematics work (Guin and Trouche, 1999). However, it is not a forgone conclusion that this will occur for all students. It is a long process and some students may be unable to reach mastery or appropriation.

Although there are many different types of technology in use in mathematics classrooms, I focussed on GCs. The main reason for this is that GCs are frequently found within A Level Mathematics classrooms in the Leeds area, although the extent of their use may range from rarely to daily use (Rodd and Monaghan, 2002). The GC is a very personal tool; it has the potential for the students to carry it with them to all lessons and also to take it home to practice further or to help with their studies. The students in my project had access to the GCs at all times, which made it an ideal tool to study for appropriation – the students had the opportunity to practice with it, master it and literally feel 'ownership' of it.

1.3 What is Appropriation?

I perceive appropriation of a GC by a student to be when the student develops a sense of ownership of the GC and has learnt not only the intricacies of how to use it but also when and where it is apposite to use it. A relationship develops between the student and their GC and they are comfortable using it. In Chapter 2 I discuss the term appropriation in more depth.

1.4 What Comes Next

The following chapter includes some definitions of terms that I consider to be central to the concept of appropriation of technology, including a discussion of appropriation and the definition that I will adhere to within this thesis. Also in Chapter 2 is a review of the literature surrounding the use of technology within high schools mathematics classrooms, as well as considering technology-centred data capture methods that have been used in previous studies. In Chapter 3 I outline my Hypothesis, the Research Areas that stem from this and related Research Questions. I provide details of the data sources and how I plan to collect and interpret the data. Chapter 4 outlines the setting of my study – the schools, the teachers and the students and provides a brief background of each. Chapter 5 describes my methodology and incorporates information on each of the data collection techniques I employed. The main data collection method I used was software for the GC (called Key-Recorder) that captured all the key-strokes made by the user. This software is examined in Chapter 6 where I also describe the advantages and disadvantages of data collection and analysis that I experienced during my study. Chapter 7 contains the data generated by my study. Due to space restrictions this is an abbreviated set of the data, but it does include all the data that are referred to in Chapter 8 Discussion of Results. In Chapter 9 Discussion of Research Questions I review each one in turn in light of my findings. Also within Chapter 9 I describe the stages of appropriation of the six students, provide examples of them moving towards appropriation and also outline some of the barriers to appropriation that they experienced during the year. The final chapter makes summary comments on my findings, considers what factors may encourage appropriation and reviews the main data collection method. It also addresses the limitations of my study and areas of further research.

Chapter 2 – Literature Review

In this chapter I define some of the terms that are central to my thesis. I also briefly review the literature focussing on educational issues arising from the use of technology within high school mathematics classrooms. I have previously written a more extensive review on this area for a directed study module for my doctorate programme (see Appendix). I conclude this chapter with a discussion of technology-centred data collection methods.

2.1 Definition of Terms

The three terms *artefacts*, *tools* and *instruments* are similar in many ways but for ease of reference and clarification of how I will use the terms, I offer three definitions that I will adhere to. The three terms, to my mind, exist on a continuum with *artefact* and *instrument* at opposite ends and *tool* in the middle.

2.1.1 Artefact

An artefact is a physical object, which requires human interaction to fulfil its potential. Wertsch (1998) says that an artefact has definite materiality and is a physical object that can be touched and manipulated.

2.1.2 Instrument

An artefact becomes an instrument when it is used for a mathematical task, even if it is incorrect use. Verillon and Rabardel (1995, p.84) write that an instrument in itself does not exist. An artefact will only become an instrument "*...when the subject has been able to appropriate it for himself ... and has integrated it with his activity*" and the user has developed a relationship with the artefact. Trouche (2003) writes that an instrument comprises a tool and a psychological component. The tool becomes an instrument through '*instrumental genesis*' which requires time and the appreciation of the potential and constraints of the tool.

2.1.3 Tool

This is a more difficult term to define. A tool is an artefact that is used to carry out tasks. It is similar to an instrument but without the human interaction. A graphics calculator (GC) is an amalgamation of different tools. Cuoco (2002) writes of CAS that they incorporate several distinct tools,

> "*...most CAS environments* incorporate *several previously developed computational media ...most CAS packages bundle together a sophisticated scientific calculator, a programming language, a graphing environment and a spreadsheet.*" (p.293)

This distinction can also be applied to GCs.

2.1.4 Appropriation

The term *appropriation* is central to my research and as there are many definitions of appropriation and it seems apposite at this stage to outline the various definitions and lay out the definition that I will adopt.

Wertsch (1998) describes a cultural tool as a 'mediational means' and the relationship between the mediational means and the agent as 'mediated action'. He writes that mediated action is characterised by some level of mastery and some level of appropriation. He goes on to define appropriation as

> "*...taking something that belongs to others and making it one's own.*" (p.53)

Wertsch (p.54) quotes Bakhtin who writes that the tool is not one's own until it has been adapted for the agent's own personal intention and made sense of it. But appropriation is not always a smooth process as it usually involves some level of resistance or friction. Higher levels of mastery may be positively correlated with appropriation but this is not always the case (Wertsch, ibid.) after all an agent could use the tool but with some level of resistance. There may be high levels of mastery but low levels of appropriation depending on the presence and level of resistance between the agent and the tool. If these levels of resistance reach high levels the agent may stop using the tool altogether. In this case they do not think the tool 'belongs' to them.

Rogoff (1995) writes about Vygotsky's definition of internalisation as the transfer of something external to internal and considers this to be similar to her definition of appropriation. In fact she sees three definitions for appropriation:

1. *"... simply the same as internalisation – something external is imported."*
2. *"... something external is imported and is transformed to fit the purposes of the new 'owner'."*
3. "*... the change resulting from a person's* own participation *in an activity, not to his or her internalization of some external event or technique.*" (p. 152)

Although I perceive internalisation and appropriation to be slightly differing states, I agree with Rogoff that appropriation does include not only the import of something external but also that it requires participation by the user to adopt it as one of their problem-solving tools.

Moschkovich (2004) considers the appropriation of mathematical practices and writes that appropriation involves taking what someone else produces for one's own use in subsequent activities. She writes that appropriation is not just imitation but that it also involves transformation of meanings, actions or goals for the individuals own purpose.

> "*Appropriation does not imply that the learner merely repeats or imitates what she appropriates. Rather, learners use appropriated meanings, actions, or goals for their own purposes and are actively involved in appropriation by transforming what they appropriate.*" (p.51)

Moschkovich agrees with Rogoff's definition of appropriation but appears to place greater emphasis on the transformation of what is being appropriated.

French researchers (Guin and Trouche, 1999; Lagrange, 1999; Artigue, 2002) see appropriation as the process by which an artefact is transformed to become an instrument. They perceive two directions in which this process takes place: towards the self and towards outside reality. Their first meaning of appropriation requires the artefact to be integrated within one's own cognitive structure (e.g., one's existing representations, available action schemes, etc.) that in general, require adaptation. This they refer to as 'instrumentation'. Their second meaning indicates that the artefact has to be appropriated to an outside context. Specific ends and functional properties, some not necessarily intended by design, are attributed to it by the user. This is referred to as 'instrumentalization'.

Guin and Trouche (1999) use the phrase 'instrumental genesis' to describe these two phases of appropriation. They state that an artefact is not an instrument until the students have used their knowledge and moved towards an instrumental genesis through learning, problem-solving and recognising some constraints (technical and command constraints). Tool use does not necessarily lead to more mathematical work but can enable students to construct their own understanding through the complex process of combining text (theory), an ICT tool and manual calculations. Students need to reflect on their findings in order to motivate themselves to improve their mathematical knowledge.

To assist in my assessment of whether students have appropriated their GC, I decided to use simplified definitions of instrumentalization and instrumentation. I see that instrumentation is when students become familiar with the tool and its technicalities. Instrumentalization is when the student knows not just how to use the tool but when it is apposite to use it. It becomes a tool in their bank of problem-solving equipment.

When a student has 'ownership' of a piece of technology and adopts it as an instrument for problem-solving, there may be some level of mastery of the technology or some feature of it and through the use of it the student will move towards "instrumental genesis". However there are other factors that must be taken into account including attitude to the technology. The student must be able to perceive the potential for the technology as a problem-solving instrument and this will lead to some privileging of the instrument.

All the above definitions of appropriation seem to share some elements but it is the general idea of Guin and Trouche's instrumental genesis and Wertsch's idea of ownership that resounds with what I perceive to be the major features of appropriation. It is an amalgamation of these two definitions that I intend to adopt for this research. To clarify this further and to aid the reader, I offer the following definition of appropriation and it is this to which I intend to adhere for this thesis.

Appropriation of an instrument is when a student feels comfortable using it, understands how to use it and when it is appropriate to use it. They understand the potential of the instrument as well as its drawbacks and during use they focus mainly on the task in hand and not on the instrument itself.

2.2 Literature Review

From reading extensively around literature centred on technology in mathematics secondary education there seemed to be a multitude of different foci. On reflection of this body of work it appeared there were four main areas: Researchers' Perspectives; Software and Hardware; Portable and Non-Portable Technology; Impact on Learning and it is these areas that I summarise below.

2.2.1 Researchers' Perspectives

The introduction of technology into mathematics education was initially thought to be a fairly straightforward process. However, with time, researchers have seen many issues emerge and this 'straightforward' process has been identified as a very complex and involved one. Researchers' perspectives will obviously impact on the style and type of research being conducted and their perspective may change or develop as time progresses and theories and areas of research develop.

In the last ten years there seems to be more emphasis on users of technology and the socio-cultural factors that may influence use or understanding as well as the study of instruments and their users (Artigue, 2002; Guin and Trouche, 1999; Lagrange et al, 2001; Lins, 2003).

The teachers' role in the classroom is changing with the introduction of technology (Mathematics Association (MA), 1992; Guin and Trouche, 1999). However, the MA seems to be unaware of the changing role of the student in the technology-centred classroom and writes about the changing face of mathematics education in fairly simplistic terms. A decade later the MA (2002) produce a document providing guidance for integrating a variety of technologies within mathematics classroom. However still at this time there is little emphasis on the changing learning experience of students apart from

> "*When used well, such tools make your students the active participants in the learning.*"
> (p.5)

2.2.2 Software and Hardware

Monaghan (1993) provides a concise summary of the main ICT instruments found in classrooms and writes that ICT in general may not have an immediate effect on students' understanding of mathematics, if at all, but it does have a dramatic effect on the teaching of mathematics. This however does not seem to be the case in 2006. Teachers are not necessarily changing their style of teaching to incorporate ICT, instead some seem to be using technology as an extra resource to accompany their usual style of teaching while others are just using it as a checking mechanism.

Students learning to use technology within mathematics education may find that it is a more complicated process that originally thought. For example the results produced by the tool may not be in a form expected by the student and therefore the student will experience some confusion interpreting the solution (Artigue, 2002). Also many pieces of technology have their own individual syntax which a student must learn at least the basics of prior to using the tool (Guin & Trouche, 1999).

2.2.3 Portable and Non-Portable Technology

Portable technology in the classroom has many advantages. It offers students the opportunity to have ready access while being personal and allowing informal use. This can result in greater levels of student motivation, confidence and understanding (Hennessy, 1998; Ruthven, 1990).

The presence of the teacher in the classroom is still essential and the teacher has a critical role to play but teaching styles need to be adapted to take account of the availability of new technology (Hennessy, 1998). The integration of portable tools into mathematics lessons provides the flexibility for the students to work either in the traditional teacher-led environment or for them to work independently and conduct their own investigations. Ruthven (1996) believes that although technology should be fully integrated it should only be used if it is suitable and fitting for students and teachers. Although this view is not uncommon Rodd and Monaghan (2002) found that GCs were virtually absent from all mathematics classrooms within the Leeds area except for A Level Mathematics classes. Even in these classes only a small number of schools use them on a regular basis and very few teachers integrated GCs into their teaching.

2.2.4 Impact on Learning

Many researchers (Papert, 1980; Kendal and Stacey, 2001) believe that the introduction and use of ICT within the mathematics classroom will enable students to improve their learning; however, there are also many conflicting views. There is still some lack of understanding as to which students benefit from the use of ICT and why and it is the factors that influence this that are not understood (Monaghan, 1993).

Ruthven (1990) found that students with a GC working on symbolisation tasks performed better than those students without a GC. He believed this was due to the students having regular access to a GC and being familiar with relationships between different representations. However teachers also have an important part to play and it is often how the teacher uses the technology that will influence the students' understanding (Lins, 2001; Kendal and Stacey, 2001) and this can vary from teacher to teacher.

The introduction of technology may even change the activity. Whereas with a traditional classroom teachers wish to remain in tight control of activities, technology can allow for more student-led investigations and misconceptions and incorrect predictions by students can become opportunities for learning (Laborde, 2001).

Guin and Trouche (1999) and Artigue (2002) believe that technology will only become an instrument for problem-solving once the student has developed a relationship with the technology over a period of time and can perceive both its potential and constraints.

2.2.5 Issues Arising That May Have an Impact on My Study

There are many different types of instrument available for use in mathematics education – software or hardware, portable or non-portable, but it is the portability of an instrument that appears to benefit the students because they have a sense of ownership, they perceive it as a personal instrument, and they can have regular and prolonged access to the technology. This will hopefully have a positive impact on my study as I am studying two groups of three students using a GC over the course of one academic year as they study for their AS Level Mathematics. The data I have collected should show how the students' attitude to mathematics and their GC develops as the year progresses as well as any changes in their motivation and confidence. Towards the end of my study I expect to find the students making decisions about when it is appropriate to use ICT and when they should rely on pen and paper techniques.

From the literature I have read, students' use of technology may be influenced by many factors and in turn the level of use of the technology will influence the student's level of understanding. I expect to find this is made evident from the analysis of the data collected during the study.

2.2.6 Technology-Centred Data Capture Methods

My thesis focuses strongly on the collection of key-stroke data from the students' GCs. This section examines the limited number of research studies that utilise different types of technology-centred data capture methods.

Burrill et al (2002) say that there is very little opportunity for insight into how students use their handheld graphing calculators as there is no direct record of their work. They believed that discussion with the student is the only opportunity to assess how the technology was used. Heid et al (1998) managed to secure an alternative method to this by recording students' key-strokes by linking the calculator to a view-screen and videoing this for future playback. Although the view-screen was hidden from the students' sight it was not entirely satisfactory because the students were aware of the video camera and the wires connecting the calculator to the view-screen. Heid concluded that this data collection method altered the students' use of the calculator because they felt self-conscious.

Thomas and Paine (2000) considered students learning to program and collected computer data files of the students' activities on the computer. The data were collected on the students' computers and downloaded at a later date. The volume of data collected was so vast that they later decided to only focus on what they considered to be 'significant events'.

Weigand and Weller's (2001) study investigated students' working styles by analysing students' actions or inputs while working on mathematical problems. They used Lotus ScreenCam which was running in the background on the students' computers, recording their inputs and creating a data file saved on the computer. It was then possible to play this file back at a later time to assess the ways in which students were working. Using this method Weigand and Weller were able to:

- assess the student activity on the computer and which representations they used
- acquire a real-time description of the students' actions
- identify students' success (or lack of success) using problem-solving strategies

It was these three studies that lead to Berry, Graham and Smith from the University of Plymouth to approach Texas Instruments with specifications for a piece of software that would run unobtrusively in the background of a GC and record the user's keystrokes. The software can be run on the TI-83+ family of GCs and is called Key Recorder. Berry et al (2006) describe three pilot studies where they were evaluating the software and assessing the working styles of students. The pilot studies involved studying the key-stroke files from the GCs used by students in Key Stage 3, A Level and undergraduate level. Using the data from the GCs they drew three main conclusions from their pilot studies:

- "*student's strategies can be identified...*"
- "*the level and type of use of calculators can be monitored...*"
- "*the key-recorder can provide details of the misuse or over-reliance on technology...*"

(p.306)

It was through contact and communication with Berry, Graham and Smith that I decided to employ the Key Recorder software for my research study. Their pilot studies focussed on students using their TI-83+ GC during mathematics lessons and they collected key-strokes during this time frame. During my study I collected data from students GCs at several times during an academic year and at times over an extended period – up to two weeks. During analysis of my data I experienced several problems. As a research tool Key Recorder provides useful details of how students use their GCs but it also has several drawbacks which can impact on the ease of analysis. In Chapter 6 I outline my experiences and perceived affordances and constraints of using Key Recorder as a research tool.

Chapter 3 – Research Questions

The primary aim of my study is to discover how appropriation of a GC influences a student embarked on an AS Level Mathematics course.

For students to use a technological instrument effectively they must be prepared to 'select' the instrument (identify it as being of use in a particular situation); remember how to use it; participate in its use; reflect on their results and findings. Having the potential to learn to use an instrument does not mean the student will master it. I believe that it is possible to appropriate some aspect of an instrument and not the whole, and likewise, it is possible to master some aspect of an instrument and not the whole. However mastery does not always indicate appropriation and vice versa. Through participation students may master some aspect of the technology and gradually continue to appropriate it, although it is not a foregone conclusion that everyone would either appropriate or master the whole instrument.

Within this study I examine students' appropriation of technology used for A Level Mathematics. Below I outline my hypothesis and research areas and questions.

3.1 Hypothesis

Students who appropriate the technology used to learn AS[4] Level Mathematics will broaden their understanding of mathematics and be able to relate their 'new' knowledge into the larger framework of mathematics.

I realise that this is a very open hypothesis and requires a narrower focus. This I hope to achieve through my research areas and research questions as detailed below in sections 3.2 and 3.3 respectively.

3.2 Research Areas

1. What is appropriation of technology and how does it manifest itself?
2. What circumstances lead to students appropriating an instrument?

3.3 Framing of Research Questions

During the course of my doctoral studies my research questions have changed. Initially I included a research area on Internalisation which I saw as the ability to use a GC without thinking how to use it or how the machine works but being able to focus on the mathematical

[4] An A Level usually consists of three AS (Advanced Subsidiary) units in the first year of study and three A2 units in the second year. An AS Level qualification can be awarded based on the modules studied in the first year.

problem and use the GC to assist in problem solving. I decided to remove this focus from my study for two different reasons: (a) appropriation seemed to develop into a larger area of study than previously anticipated and (b) internalisation seemed such a difficult area on which to collect data. As a result of rethinking my research questions, I am left with a more in-depth study of appropriation.

Within both research areas I have outlined specific research questions. Each of these research questions is cross-referenced with a data source and different aspects of student use of a GC have been identified which I refer to as a 'measure'. Each measure has been designed to generate data on different aspects of appropriation which, through my analysis and interpretation, contribute to my understanding of the student's level of appropriation of the GC.

I gathered a great quantity of data from a variety of sources: interviews, observations, GC key-stroke data, and students' journal entries. Below I link each data source to the research questions but to summarise (in Table 3.1):

Data Sources	
A	Interviews
B	Classroom Observations with Key Recorder Data
C	Key Recorder
D	Classroom Observations with Key Recorder and Stimulated Recall Interviews
E	Student Journal

Table 3.1 Key to Data Sources

The measures, detailed below, are linked to methods of collecting data on students' overt behaviour when using GCs and scientific calculators within the scope of AS Level Mathematics. Through my interpretation of the data I ascribed mental states to the students with respect to their use of the GC and scientific calculators. For example, using the measures I collected data on the frequency a student uses a GC and for which topics. While this is measurable I will use my interpretation of the data to determine if a student has appropriated the GC, which is a mental process and a mental state that I cannot measure.

3.3.1 Research Area 1

My interest here is

What is appropriation of technology and how does it manifest itself?

Appropriation will have taken place when a student experiences ownership of the technology and adopts it as an instrument for problem-solving. They may need some instruction but they are keen to use it. Appropriation will manifest itself as the student willingly and frequently using the technology whenever they are instructed or whenever they feel it is necessary. If a student has not appropriated the instrument they will be reluctant to use it, may not be able to see its potential for problem solving and may possibly need a considerable amount of encouragement, help and instruction when prompted to use it.

Appropriation itself cannot be measured but various measures can be made that inform this area.

3.3.1.1 Research Questions from Research Area 1

RQ1a. Can appropriation be described in terms of (i) unprompted use and (ii) own strategies?

RQ1b. Does appropriation manifest itself in consistent ways among individuals and if not, how does it vary?

Two research questions were devised for this research area because I thought it necessary to analyse appropriation from an individual student's perspective and what constitutes appropriation of a GC (RQ1a), but I also want to make comparisons between different students about how they appropriate a GC (RQ1b).

3.3.1.2 Measures

RQ	Measures	Data Sources
1a(i),(ii)	a) Extent of use of a scientific calculator	A, B, D, E
1a(i),(ii)	b) Student's responses to teacher's prompts to use GC	B, D
1a(i),(ii)	c) Evidence of unexpected use	A, B, C, D, E
1a(i),(ii)	d) Use of GC out of class	A, C, E
1a(i),(ii)	e) Extent of use of GC	A, C, E
1b	f) Different subject areas where the GC is used	A, B, C, D, E
1b	g) Frequency of use of GC with respect to other tools	A, E
1b	h) Evidence of a student's succinct use of a GC with few errors	B, C, D
1b	i) Apposite use of the GC	A, B, C, D, E

Table 3.2 Measures and Data Sources for Research Area 1

I developed nine different measures to address RQ1a (i) and (ii) and RQ1b. As a group they cover all the areas concerning use of GCs that I consider to be relevant to appropriation. The students used their scientific calculator during their earlier mathematics education and the way in which their use of the scientific calculator changes after the introduction of a GC will provide interesting data. If a student uses their GC to the exclusion of their scientific calculator I will interpret this as evidence she/he has appropriated their GC. However if a student continues to use their scientific calculator on a regular basis and uses their GC only for tasks that a scientific calculator cannot do then I will interpret this as the student not appropriating the GC. While these are extremes of use, there may also be students who make substantial use of their GC but only in specific areas – for graphs, or statistics. This evidence will provide evidence that such students have partially appropriated the GC – as a graphing instrument or as a statistical instrument, or indeed they may have appropriated multiple aspects of the GC. This area is covered by measures (a), (f) and (g). Students' use of a GC outside the mathematics classroom, whether it is for mathematics homework or within other subject areas, will indicate a student has appropriated the GC. This area is covered by measure (d), (e) and (f).

If a student makes similar errors on their GC throughout the course then this indicates that the student is not beginning to appropriate their GC. However conversely, if the student seems to progress in which type of error they create and how they manage their errors this will indicate a positive step towards appropriation. This area is covered by measure (h).

Students taking full advantage of some of the features of a GC to solve problems can be considered to appropriating their GC. If they continue to use simplistic calculations to reach a solution for a given problem this may reflect that the student is reluctant to rely on the GC to give an accurate answer and therefore it indicates that the student is experiencing problems appropriating their GC. This area is covered by measure (i).

A student's type of use of their GC is a good indicator of the extent of the student's appropriation of the GC and it is measure (b) and (c) that focus on this area. There are three different types of use that are of significant interest to me: unprompted, independent and unexpected use. These three categories indicate varying levels of autonomy. *Unprompted use* is when a student uses the GC without being told to but uses it for doing something that they have already been shown. *Independent use* is when a student uses the GC for doing something that they have not been shown but it is within the scope of mathematics already taught. Measure (b) will identify how the student responds to teacher instruction and if the student developed any strategies that were independent of the teacher. *Unexpected use* is when the student uses their GC for mathematical or non-mathematical processes that are outside of the scope of mathematics already taught. Measure (c) will identify instances of when the student is using the GC in this way. There are close links between the three categories – independent use of a GC may also be seen as unprompted use, however the difference lies in what use of the GC has been previously taught; unexpected use may also be seen as independent use, however the difference is independent use is within the scope of AS Level Mathematics. There may be 'grey areas' in ascribing these categories to students' use but these categories are useful in both tracking students' use over time and evaluating evidence as to whether or not they can be said to have appropriated their GC. I collected data using some of the same measures as above to provide evidence of unprompted, independent and unexpected use.

Type of Use	Measures
Unprompted Use	(b), (d)
Independent Use	(b), (d)
Unexpected Use	(c), (d), (f)

Table 3.3 Type of Use Observed & Related Measures

If a student displays any of these three types of use it will indicate that she/he has begun the process of appropriating the GC.

3.3.1.3 Interpretation

Data from the five data collection methods as described above were used to address these research questions and provided evidence for the seven measures within Research Area 1. Each measure is not enough on its own to inform the research area or indeed to answer the individual research questions, but it is a combination of all the measures that inform this area.

Measure (a) provides data as to whether the student uses a scientific calculator or not. Further information was collected to determine with which activities the student was involved. Data was gathered from interviews, observations of class and student activity and from the student journals. This measure goes some way to identify how often the student uses their scientific calculator despite the presence of or even encouragement to use the GC. Use of a scientific calculator and reluctance to use a GC is seen as an indication that the student has appropriated the scientific calculator and not appropriated the GC. Conversely, limited or no use of a scientific calculator and greater use of a GC indicates that the student has begun the process of appropriating the GC.

Measure (b) provides data as to whether the student uses their GC exactly as prompted by the teacher or not. Further data were collected to identify the class and teacher activity and how the student responds. Data were gathered from observations with the Key Recorder software. This measure identifies if the student follows the teacher's prompts to use the GC exactly or if she/he privilege their scientific calculator despite encouragement to use their GC. Initially I expect the student to imitate the teacher's keystrokes with this changing over time to the student using their GC in an independent or unprompted manner. A student who follows the teacher's prompts, keystroke by keystroke, will have hardly begun the appropriation of the GC as she/he are requiring direct instruction to use their GC. However, a student who works unprompted by the teacher, (using their GC in a way previously shown to work through mathematical problems), or who works independently of the teacher, (using the GC in a way not taught by the teacher,) will be in the process of appropriating the GC.

Measure (c) provides data indicating whether or not the student displays unexpected use of the GC. Further information was collected to determine how the student used the GC in unexpected ways – either mathematical or non-mathematical. Data were gathered from interview, observations, Key Recorder and the student journals. This measure begins to explain if the student is using the GC in ways other than those taught or encouraged by the teacher. This might be using the GC for writing messages or exploring other features of the GC, for example drawing polar graphs or using the statistical trialling programs (rolling dice, spinners etc.). Unexpected use of the GC, whether it is for mathematical or for non-mathematical work, indicates some level of appropriation of a GC.

Measure (d) provides data as to whether or not the student uses their GC out of class. Further information will be gathered identifying the activity in which it was used – mathematical or non-mathematical. Evidence was gathered using interviews, Key Recorder and the student journals. This measure identifies unprompted and independent use and how the GC was used. Unprompted, independent and unexpected uses are indicators that a student has appropriated the GC.

Measure (e) provides descriptive data about which activities the student is engaged in when using the GC. This evidence was gathered from interviews, Key Recorder and the student journals. The student was asked to gauge their use of the GC and the Key Recorder data were used to corroborate this. Together these provide a reliable indication of the extent of the student's use of the GC out of class. A student, whose use of their GC outside mathematics classes is quite substantial and regular, will be in the process of appropriating their GC.

Measure (f) provides data of the subject area when the GC is used (Pure Mathematics, Statistics, Discrete Mathematics and non-mathematics work). This evidence was collected from interviews, observations, Key Recorder and the student journals. This measure identifies not only the areas where the student uses the GC most but also indicates areas where the student makes limited use or no use of the GC. As a GC is an amalgamation of many instruments, (Cuoco, 2002) it is possible that a student could appropriate some of the GC's features but not others and there may be evidence that a student uses the GC in an unexpected manner. This may be directly related to one of the subject areas. A student appropriating the statistical analysis feature of the GC may not appropriate the graphing instrument that is required for AS Level Pure Mathematics topics. An instance of this should be highlighted by this measure. Partial appropriation of the instrument may encourage students to appropriate other instruments within the GC by developing a positive approach and attitude to the GC and perceiving its value as a mathematical instrument.

Measure (g) provides data of the form: spreadsheet, scientific calculator, mental calculation… i.e. the instrument in use by the student for mathematical work. Further information was also gathered and on the extent of use of the GC. This evidence was collected from interviews and the student journals. This measure will indicate which instruments the student has appropriated or is in the process of appropriating. Privileging of the GC will indicate the student is appropriating that instrument.

Measure (h) provides evidence to show what type of errors the student makes – mathematical, navigational, syntactical or other and how the frequency of these change over time. It will identify if a student is learning from errors they made or if they are making similar types of error throughout the year of study.

Measure (i) provides evidence about which method a student uses to solve specific problems.

A single measure from the list above is not enough to identify if a student has appropriated a GC, however considering all these measures together will contribute to answering the two research questions generated from the research area. I will be able to report on all of these measures but my interpretation will contribute to these answers and will produce qualitative comment on each.

3.3.2 Research Area 2

My interest here is

What circumstances lead to students appropriating an instrument?

There are potentially many factors that may influence a student's use of technology, more specifically what influences a student to appropriate an instrument? What are the factors that play a part in the appropriation of an instrument by a student: teacher or peer support (or lack of support); a student's attitude to technology on the whole or the GC in particular; the student's attitude to mathematics? Some people may never appropriate a specific instrument.

3.3.2.1 Research Questions from Research Area 2

RQ2a. What enablements are there to a student appropriating an instrument?

RQ2b. What obstacles are there to a student appropriating an instrument?

I divided this research area into two as I thought there would be factors that positively influence students (RQ2a) as well as negatively influence students (RQ2b).

3.3.2.2 Measures

RQ	Measures	Data Sources
2a	a) Comments from students on the advantages or perceived potential of using a GC	A, B, D, E
2b	b) Comments from students on the disadvantages or perceived constraints when using a GC	A, B, D, E
2a,b	c) Comments from students about the level of support or training needed	A, D, E
2a,b	d) Comments from students about the level of support or training received.	A, B, D, E
2b	e) Types of difficulties faced when using a GC	A, B, C, D, E
2a	f) Success in using a GC for problem-solving	B, D, E
2a,b	g) Changes in a student's level of confidence when using a GC	A, D, E

Table 3.4 Measures and Data Sources for Research Area 2

I have developed seven measures to help answer RQ2a and RQ2b. Together these measures are designed to gather evidence on the influential factors for a student appropriating a GC. The majority of measures used to inform these research questions are, by nature, based on factors or influences as described by the individual students. The data to inform these research questions will be collected from interviews, student journals, stimulated recall interviews as well as classroom observations. There may be other factors influencing a student's appropriation of technology but for my study they are inaccessible and I will only be able to report on those outlined by the individual students. I will also consider the types of difficulties faced by the student when using their GC. This could take the form of technical problems, individual's attitude or different syntax errors.

A student is more likely to appropriate their GC if they can perceive the benefits and drawbacks associated with using this instrument. The data collected should provide evidence in this area and will be covered by measures (a) and (b). Initially a student is likely to need some instruction and guidance as to how to use their GC but that the need for this support will decrease as the year progresses. While I am not able to collect the frequency with which support was needed or provided the interviews and journal entries will provide evidence of the type of support needed or received during the year of study. This will be collected with measures (c) and (d).

A student who is successful in their problem-solving activities with the GC is likely to experience an increase in their confidence using the GC as an instrument. Data informing this area will be collected using measures (f) and (g).

If a student is on the path to appropriating their GC then I would assume that the number and type of difficulties would change as the year progressed. Initially there would be a significant number of syntax errors, navigation issues and errors associated with operating the GC itself and these would decrease through the year. There will be other types of difficulties that would also decrease over the course of the year.

3.3.2.3 Interpretation

The evidence gathered will come from classroom observations, interviews with students as well as student journal entries. It is a combination of all five measures that will inform the research area.

Measure (a) provides data on whether the student perceives any advantages or potential of the GC. This evidence will mostly be from a student's comments through interview or journal entry but data from the classroom observations may also illustrate if the student is relating what their teachers perceives as advantages or if they are making independent comment about the technology. Measure (b) provides data on whether the student perceives disadvantages or constraints when using their GC. The evidence will again be mostly from student's comments through interviews or journal entries but data from classroom observations may provide valuable results. Measure (c) provides data as to how much support the student felt they needed to operate the GC as well as any difficulties they faced. I envisage that a student's need for support will be quite intense at the start of the course but as the year progresses the student will have less need for it. Measure (d) provides data on how much support to use their GC the student received during the AS Level Mathematics course and where the support came from – manual, teacher instruction, peer instruction or other. Measure (e) indicates what type of difficulty the student faced – operation of the GC or mathematics related or other and at what part of the year. Measure (f) provides evidence about how the student approaches mathematical problems and how they use their GC to help solve these problems. Measure (g) provides evidence about the student's level of confidence using their GC and if this changes during the course of the year.

Chapter 4 – The Setting

The two schools I approached to help with my study are local education authority schools within the Leeds area. Both are schools with students aged 11 -18, have an ethnic mix in keeping with that of the authority as a whole and are both mixed sex schools. I chose to work with two schools as this allows for different approaches to graphics calculators to be observed and comparisons made.

4.1 The Schools

I contacted the Heads of the Mathematics department within two schools in the Leeds area who, it was thought, may be willing to help me with my project. I was fortunate in that both heads of department agreed to allow me into the school to follow some of their students for the whole of the academic year September 2003 to July 2004. I decided to collect data over the whole academic year as I would be able to ascertain how the use of the GCs by students developed over this period.

4.1.1 School A

The school is a mixed comprehensive school for pupils aged 11 to 18 years of age, is situated in north Leeds and, at the time of writing, is heavily oversubscribed. There are approximately 1100 students on roll and nearly 180 students in the sixth form. They received a very favourable OFSTED[5] inspection report (October 2000) which states that attainment of most pupils was above the national average and describes the school as an effective and improving school.

Pupils are described as well motivated with good behaviour and good attitude within the classroom. At Key Stage 4 attainment is perceived to be above the national average for mathematics and while attainment in the sixth form is also seen as above the national average there seems to be some fluctuation. However, the report does state that progress in A Level classes is good.

This school has two AS Level Mathematics classes merging into one A2 class in the Year 13. The AS Level modules are Pure 1, Pure 2 and Statistics 1 which leads to an AS Level in Pure Mathematics with Statistics. There are 21 students studying AS Level Mathematics and 18 students studying for an A Level in Pure and Applied Mathematics.

For AS/A2 Level Mathematics the school follows the OCR examination board. There are eight teachers within the department – 7 full-time and 1 part-time. There are seven teachers on the AS/A2 programme.

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[5] OFSTED – the Office for Standards in Education - is a non-ministerial government department established under the Education (Schools) Act 1992 to take responsibility for the inspection of all schools in England.

The school's Head of the Mathematics department describes their policy for GCs as not actively integrating the use of GCs into mathematics lessons. The teachers are not expected to teach using the GC or provide tuition on how to use them, although they do provide GCs for the students to buy at the beginning of the AS Level programme – Sharp EL9450. The main reason given for this is to ensure all the students have the same model of GC.

4.1.2 School B

The school is a mixed comprehensive school for pupils aged 11 to 18 years of age. It is situated in a former mining area and there are many pupils who come from homes with a low socio-economic background. The school is increasing in popularity and at the time of writing was oversubscribed. There are approximately 1350 students on roll throughout the whole school with approximately 130 students in the sixth form.

School B received a very favourable OFSTED inspection report saying that it is a very good and improving school. The schools GCSE results in 2001 were slightly below the national average but had a trend of steadily improving results. There seemed to be little difference in attainment between boys and girls.

At the time I conducted my research the school's most recent OFSTED report, dated September 2002, stated that the sixth form (years 12 and 13) was very effective and its standards and results showed significant improvement with 'good' or better teaching of mathematics. The students were perceived to have

> "*...high levels of respect for their teachers and are, therefore willing to work very hard.*" (para. 23 p.17)

and the students' confidence was developing as a result of teacher encouragement. There was one reference to the use of graphical calculators at GCSE level, for straight line graph work, where they were referred to as being used as a checking mechanism for the students (para.87 p.36). Within the sixth form section of the report there is only reference to scientific calculators saying that at times the students did rely too much on scientific calculators for simple calculations (para.173 p.58).

School B has two AS Level Mathematics classes in year 12 merging into one A2 classes in Year 13. The AS Level Mathematics modules are Core (Pure Mathematics) 1, Mechanics 1 and Decision Mathematics 1 leading to an AS Level in Pure and Applied Mathematics. The school has 19 students studying AS Level Mathematics and five students studying A2 Level Mathematics. The A2 course on offer is Pure and Applied Mathematics.

The examination board used by the school for AS/A2 Mathematics is Edexcel. There are nine teachers within the Mathematics department – seven full-time and two part-time. There are five teachers on the AS/A2 programme.

The Mathematics department describes itself as actively encouraging the use of GC and referring to them on a regular basis during classes. Students in Year 7 – 11 have usually had some experience of GC within the mathematics classes for some statistics work.

In the year after my data collection, September 2004 to July 2005, school B changed their AS/A2 Level syllabus to one which included a non-calculator paper. This change did not affect my study as the school began teaching to the new syllabus only after my data collection phase had ended.

4.2 The Teachers

School A – From my observations it became apparent that although the school said they did not support GC use in fact this is not strictly the case. One teacher did make continued reference to the GC through the classes I observed and taught the students how to use it. However it was not clear if this was due to my presence in the classroom and school. It may have been his interpretation of little or no use of the GC. This level of use of the GC did diminish as the year progressed therefore I concluded that the teacher did attempt to integrate the GC into his lessons as a result of my presence in his classroom.

School B – All AS Level Mathematics students are required to buy a TI-82 GC for AS and A2 Level Mathematics. Although the students have access to GC during every lesson there seemed to be only a small amount of work that took advantage of the full potential of the GC.

The examination questions for AS and A2 Level Mathematics are structured so that those with a GC have no advantage over those without and in some examinations the GC is not permitted. As a result the teachers in both schools promote the GC as an instrument to check solutions. The impression given by school B was that despite my presence in the classroom over the year the teachers did not change their level of use or style of use of the GC. However it did appear that the teachers in School A did change their level of use of GCs initially and they made many references to it but this level of use did not continue for the whole of the academic year.

4.3 Students

My study focuses on three AS Level Mathematics students from each school (n = 6) although one student from school B withdrew from all his AS Level courses at the end of the first term, December 2003. Although I selected the schools in this study the students were all volunteers. I visited the two classes (one from each school) at the beginning of the year and asked for three volunteers from each.

4.3.1 Students from School A

4.3.1.1 Ann

Ann achieved a B grade at GCSE Mathematics Intermediate Level in July 2003. She has a very friendly personality and was willing and eager to talk to me from an early stage. Her other AS Level subjects were Biology, Psychology and English Language. She found the whole of the AS Level Mathematics course extremely challenging and her teachers expressed concern about her understanding and her low level of attendance. They believed that the two factors were inextricably linked.

Ann was an eager volunteer for my project however as the year progressed her lack of attendance meant that I was unable to collect data from her or her GC. She submitted only 2 journal entries during the year and was unavailable for interview on several occasions. I see this as a response to her personal concerns about her level of understanding of the mathematics being studied and being unwilling to be confronted by it.

Ann decided very early in the course, December 2003 that she would not be taking A2 Level Mathematics course the following year. Her results for AS Level Pure Mathematics with Statistics are as follows:

	P1	P2	S1	AS grade
Jan 2004	U			
Jul 2004		U	U	U

Table 4.1 Ann's AS Level Mathematics Results

4.3.1.2 Max

Max achieved an A* at GCSE Mathematics in July 2003. He is a very pleasant individual and although he is relatively quiet, he is able to make conversation whenever the opportunity arises. His other AS level subjects were Physics, Chemistry, Biology and General Studies. He started the year as a high achiever but as the year progressed his work showed signs that he found the work challenging.

Max was an eager volunteer for my project and signed up straight away. He was very conscientious about attending interviews and other data collection sessions and made every attempt to make alternative arrangements if he was unable to attend. Max was a regular contributor to his journal during the year and made eight entries.

Max's results for AS and A2 Level Mathematics are as follow:

	P1	P2	S1	AS Grade	P3	S2	M1	A2 Grade
Jan 2004	A							
Jul 2004		A	A	A				
Jan 2005					A			
Jul 2005						A	A	A

Table 4.2 Max's AS and A2 Level Mathematics Results

After the completion of his A Levels Max plans to study medicine at university or to enter politics.

4.3.1.3 Sam

Sam achieved a grade B at GCSE Mathematics Intermediate Level in July 2003. He appears to be a slightly nervous person and eager to please. His other AS Level subjects were Art, English Literature and General Studies. Sam found the work through the year to be very challenging and his teachers expressed concern about his level of understanding.

Sam appeared eager to participate in my project and was quick to volunteer. He attended all the interviews and nearly all the other data collection sessions however he was reluctant to submit many journal entries – only 2 during the year, one of which was a verbal report. This I see as a response to him being unsure of what to write. While I explained that it is his opinions and experiences that I was interested in it appeared that he did not know exactly what the 'correct' opinion was. From this I assumed that the interviews and journal entries with Sam contain data that may not truly reflect his views and opinions but instead contain what he considered to be what I wanted to hear. I took this into account when analysing Sam's data.

Sam's results for AS and A2 Level Mathematics are as follow:

	P1	P2	S1	AS Grade	P3	S2	M1	A2 Grade
Jan 2004	U							
Jul 2004	E	U	B	E				
Jan 2005					U			
Jul 2005						U	B	E

Table 4.3 Sam's AS and A2 Level Mathematics Results

Sam would like to study architecture at university.

4.3.2 Students from School B

4.3.2.1 David

David achieved an A grade at GCSE Mathematics in July 2003. He is a very friendly individual and was willing and eager to talk with me. His other AS Level subjects were General Studies, Chemistry, Physics and French. David found some of the AS Level Mathematics difficult and on occasion he allowed himself to be distracted by his classmates.

David was a reluctant volunteer to my project and considered it carefully before agreeing to participate. This was only after his friend, Steve, had joined. His attendance was good throughout the year and was always available for data collection or discussion, although sometimes he forgot to pick up his GC after I had removed the latest data file. David made five journal entries during the year but most of them have been prompted by me and so were on the whole were either handwritten or verbal entries.

David's results for AS and A2 Level Mathematics are as follow:

	Core 1	D1	S1	AS Grade	Core 2	Core 3	Core 4	A2 Grade
Jul 2004			E					
Nov 2004		C						
Jan 2005	C				C			
Jul 2005						U	U	D

Table 4.4 David's AS and A2 Level Mathematics Results

David hopes to be a pilot in the RAF but this may not be possible due to health reasons but he is considering a career as a commercial pilot.

4.3.2.2 Sarah

Sarah achieved a B grade at GCSE Mathematics when she took it in year 10, July 2002 and an A* grade at GCSE Mathematics when she took it again in July 2003. She was extremely friendly and eager to discuss her views and experiences of using her GC with me, although her frequency of communication reduced as the year progressed. Her other AS Level subjects were Physics, Further Mathematics & ICT. Over the course of the year Sarah seemed to enjoy her Mathematics course and whenever she found the work difficult she would rise to the challenge. Sarah had designed a web-site with her friend and claimed to have a great interest in all things technological.

Sarah was an eager volunteer for my project and was the first student to agree to participate. She was a regular contributor to her journal and submitted frequent and unprompted entries by email. Sarah was eager to help in my study and was always available for interviews, classroom observations or key-stroke data collection.

Sarah's results for AS and A2 Level Mathematics are as follow:

	Core 1	D1	S1	AS Grade	Core 2	Core 3	Core 4	A2 Grade
Jul 2004		B						
Nov 2004			A					
Jan 2005	A				A			
Jul 2005						A	B	A

Table 4.5 Sarah's AS and A2 Level Mathematics Results

Sarah hopes for a career within mathematics, possibly teaching.

4.3.2.3 Steve

Steve achieved a grade B at GCSE Mathematics Intermediate Level in July 2003. He appeared to be a very quiet individual with teachers and with myself but was quite chatty with his own friends and neighbours in the class. He was easily distracted in class and this at times seemed to contribute to his difficulty in understanding some of the topics. Steve's other AS Level subjects were Physics and ICT.

Steve was an eager volunteer for my project however he was reluctant to talk about his use of the GC and made only two journal entries. He withdrew from all his AS Level courses after one term and left the school.

Chapter 5 – Methodology

5.1 The Approach

This research study may be broadly described as socio-cultural and as Lerman (2001) states a socio-cultural perspective means not only examining school practices and the context in which students learn but also examining mediated action and the individual students. He uses the analogy of 'zooming in' to refer to the focus on the student and 'zooming out' to refer to the context in which students learn.

> "...*the task of researchers working with these (socio-cultural) theories in mathematics education is to make links between structure and agency and between culture, history and power and students' learning of mathematics.*" (ibid. p.90)

The student is affected by the context in which they learn and the environment is also affected by the presence of the student. Lerman says that researchers must consider the student-in-the-mathematics-classroom-in-student (ibid. p.98) and in fact during analysis all aspects of the environment should be considered.

For this research project I used a case study approach. As Lincoln and Guba (1985) state, a case study can provide a 'thick description' of a situation and its aim should be to transport the reader to the setting of the study where they will be familiar with all its details (p.214). Case studies can illustrate a given situation and enable a set of circumstances to be described more fully than with quantitative analysis. They can present rich and colourful descriptions of events relevant to the case (Cohen, Manion and Morrison; 2003). Robson (1993) says a

> "...*case study is a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence.*" (p.5)

The main drawback of using case studies is that they describe a certain situation at a certain place and at a certain time and this limitation should be borne in mind throughout the whole process of analysis. Yin (1998) advocates adopting a multitude of data collection methods during case studies to apply the idea of triangulation and establish if evidence from the multiple sources coincide.

I this study I focus on a small number of multiple cases, a case being a student-with-a-GC-in-a-school, and I describe their characteristics. The vast majority of my data will be qualitative which should provide a great deal of descriptive data detailing how, when and why the students use their GCs and what factors influence their use. As Cohen, Manion and Morrison (2003) state

> "*Qualitative research... draws the researcher into the phenomenological complexity of participants' worlds; here situations unfold, and connections, causes and correlations can be observed as they occur over time. The qualitative researcher seeks to catch the dynamic nature of events, to seek intentionality, and to seek large trends and patterns over time.*" (p. 306)

I adopted a naturalistic paradigm for my study and although they are difficult to define they will develop over the period of the study (Lincoln and Guba, 1985). Within a naturalistic inquiry there are multiple realities, each individual having a different one. Lincoln and Guba (ibid.) write that in order to research a situation a flexible methodology is required whereby the data are collected from the natural setting usually using qualitative methods.

> *"The naturalist elects to carry out research in the natural setting ... because naturalistic ontology suggests that realities are wholes that cannot be understood in isolation from their contexts."* (ibid. p.39)

The rest of this chapter outlines the methodology I employed to collect data to address my research questions. In section 5.2 I provide brief details of the pilot study I conducted prior to my study and in section 5.3 I describe the data sources I used during my study and explain why I chose those particular methods. Next, in section 5.4, I provide details of the data analysis phase of my study and outline the coding scheme I used to record the different themes within the data. Conducting any research project can be fraught with logistical difficulties and in section 5.5 I summarise the particular difficulties I experienced whilst conducting my study. I conclude this chapter by considering the reliability and validity of my study.

5.2 Pilot Study

I conducted a small pilot study by visiting three schools. The pilot study was conducted as a way of understanding what is happening now with students and their GCs. During this study I observed students in AS Level Mathematics lessons where they were being taught how to use their GCs as problem solving tools. I also observed a class where the students had access to GCs and scientific calculators and were offered the opportunity to choose which tool to use. I interviewed two students who were using a GC on a daily basis and I also asked a group of six students to write a brief account of their use of GCs in their mathematics lessons.

The classroom observations led me to refine my ideas of appropriation and consider that there are a variety of factors that contribute to a student appropriating technology and also that students will appropriate a GC to different degrees. The pilot study enabled me to frame my hypothesis and research questions and develop my initial interview schedules.

5.3 Data Sources

I collected data from six students taken from two schools in the Leeds area.[6]. The data collection phase lasted one academic year: September 2003 to July 2004. This period of data collection enabled me to establish how the use of GCs by the students' developed over the course of a year. The primary data sources I used were:

- interviews with students
- key-stroke data from the students' GCs

[6] More information on the schools, students and teachers can be found in Chapter 4 – The Setting.

- classroom and student observations with key-stroke data from the students' GCs
- classroom and student observations with key-stroke data from the students' GCs shortly followed by stimulated recall session with the students reviewing their GC use
- student GC journals

I also made some field notes after any informal chats with the students or teachers.

I chose to use a wide variety of data collection methods not only as I thought this would enable the data from the different sources to provide some corroboration of my findings but also as Yin (1998) writes that one of the aspects of the definition of case studies is the reliance on multiple data sources.

Initially I drew out a schedule for my data collection over the year trying to spread out the different methods. The actual schedule of data collection (Table 5.1) varied very little from the planned schedule, the only difference being that in the spring term neither group of students were available for an Observation with Key Recorder.

Autumn Term

Weeks	Date (commencing)	Type of Data
2-3	15th Sept	Interviews
4-5	29th Sept	Observations with Key Recorder
6-7	13th Oct	Key Recorder
8-10	3rd Nov	Observations with Key Recorder & Stimulated Recall
11-12	24th Nov	Observations with Key Recorder
13	8th Dec	Key Recorder

Spring Term

Weeks	Date (commencing)	Type of Data
15-16	5th Jan	Interviews
17-18	19th Jan	Key Recorder
21-22	23rd Feb	Key Recorder
23-24	8th Mar	Observations with Key Recorder & Stimulated Recall
25-26	22nd Mar	Observations with Key Recorder

Summer Term

Weeks	Date (commencing)	Type of Data
27-28	19th Apr	Key Recorder
29-30	4th May	Observations with Key Recorder
31-32	17th May	Observations with Key Recorder & Stimulated Recall
33-34	7th Jun	EXAMS
35-36	21 Jun	Interviews & Key Recorder

Table 5.1 Actual Schedule of Data Collection

The frequency of these data collection methods is seen below in Table 5.2:

Data Collection Type	Frequency
Interviews with students	3
Key-stroke data from the students' GCs	6
Classroom and student observations with key-stroke data from the students' GCs	4
Classroom and student observations with key-stroke data from the students' GCs shortly followed by a stimulated recall interview	3
Student GC journals	Voluntary contributions

Table 5.2 Frequency of Data Collection

Although in the table above I identify different types of data collection, these are in fact combinations of 5 different data collection methods – interviews, key-stroke data, observations, stimulated recall interviews and student journals. Below I go into further detail about these data collection methods.

5.3.1 Interviews

As I had made the decision to collect qualitative data for my study I decided to use interviews which are frequently used to collect this type of evidence. (Bryman, 2001; Robson, 2002; Cohen, Manion and Morrison, 2003) I also thought that the students would respond more positively if they were allowed to talk about and describe factors and issues that they felt were important while at the same time affording me the opportunity to follow up student's views with further questioning. I planned to interview the students three times within the academic year, each time using the hierarchical focussing technique as developed by Tomlinson (1989). The students had the opportunity to describe their views of their own realities using their own language. Theoretically, hierarchical focussing allows the interviewer to ask an initial access question and then the interviewee can talk until they have exhausted that area of enquiry when the interviewer can pose another question or direct the interviewee to an area that has yet to be covered. This technique allows the interviewee to not only talk about the issues and areas that are of importance to them but also enable the interviewer to note down which topics were brought up by the interviewee without prompting therefore indicating that area is of significance to the interviewee. As there is a reduced amount of prompting or question-asking by the researcher the level of influence the researcher may have over the respondent will be decreased. The method of interviewing seems to be taken more seriously by the respondents therefore their true feelings are related and this will ultimately provide valid data.

In reality, the students in my study found it very difficult to talk about their GC, how they used it and their opinions and experiences. They seemed to be more at ease responding to questions rather than expressing their opinions freely. The hierarchical focussing technique I aimed to employ did not produce such a free-flowing stream of consciousness as I first hoped. The students began to talk about what they thought I wanted to hear or what they had used it for this week and almost immediately afterwards were reluctant to continue. They appeared to be more comfortable being asked straight questions to which they could focus their answers. As a result it was this style of interview that I resorted to as the data collection progressed. All the interviews were tape-recorded and transcribed as soon as possible after the event, which helped to provide an on-going picture of the students' use of their GCs.

5.3.2 Key-Stroke Data from Students' GCs

I was intrigued to find out when and how the students used their GCs therefore I also gathered key-stroke data from the students' graphical calculator using a piece of software called Key Recorder. This program creates a file within a GC that will record every keystroke made by the user. Each data collection session covered one or two weeks of use at home and school or one observed lesson. I was then able to replay the data file containing the student's keystrokes as necessary. This evidence provided a fuller picture of the students' activities with a GC.

The Key Recorder software is a very unobtrusive data collection method – a student will be virtually unaware of it collecting data and it should have little or no influence on their usual GC activities. The data should also be able to provide some indication of the students' work processes with the GC and how they use it. I used Key Recorder in conjunction with observations and stimulated recall sessions, which included work outside the classroom and outside the subject area thereby tying in three types of data collection and hopefully providing a much clearer picture of the student's level of appropriation of the technology.

Further information on this type of data collection method can be found in Chapter 6 Key Recorder and in Sheryn (2006).

5.3.3 Classroom Observations

There are many different types of observational approaches – highly structured, semi-structured, unstructured – but in general, all types of observation can bring about an understanding of what happens in a classroom. Cohen, Manion and Morrison (2003, p.305) write about the advantages of observations being the opportunity to gather data on different settings:

- physical: the physical environment and its organisation
- human: the organisation of people and their characteristics (gender, age, race…)
- interactional: the types of interaction occurring – formal, informal, planned, unplanned, verbal, non-verbal,…
- programme: resources and their organisation; pedagogic styles; curricula; organisation

I decided to conduct unstructured observations of teacher and student activities within the AS Level Mathematics classroom and the intention was to record as much detail as possible about the behaviour and activities of people present. Cohen, Manion and Morrison (ibid.) write that the advantages of an less structured observation approach is that

> "*… it is responsive to what it finds and therefore, by definition, is honest to the situation which it finds.*" (p.306)

I was particularly interested in how often the students use their GCs, what they use them for and what prompted them to use them. I made note of the teacher activities within the classroom, as well as activities of the students in my project and their peers. My observations were conducted as a non-participant observer and I observed the students seven times during the year. Bryman (2001) describes a non-participant observer as when

> *"...the observer observes but does not participate in what is going on in the social setting."* (p.163)

This approach meant I could observe the students without unduly influencing their process of learning and understanding but had the opportunity to talk to them and observe them as they work. I hoped to take the role as complete observer but as Robson (2002) says the presence of a researcher in the classroom will affect the students to some extent. However, there were times during my classroom observations when the teacher made reference to my presence therefore my status as a non-participant observer was potentially altered. There were occasions when the teacher asked my advice on using the GC, struck up conversation while the students were working on a task or alternatively the students themselves began talking to me either for advice about the GC, help with their mathematics or tried to engage me in some social conversation.

The observations in themselves are limited in the type of data they produce and their usefulness but in these observations I also included details of the teacher activities at the time e.g. training students to use their GCs; directing students to problem-solving activities etc. This provided useful information that enabled me to cross-reference the teacher and student activities to determine how much the students use the GCs without direct instruction from the teacher.

Observing a group of people interacting can be fraught with bias, which can impinge on reliability and validity but combining observations with other data sources can provide corroboration (Cohen, Manion and Morrison; 2003) and so increase the validity of the data.

5.3.4 Stimulated Recall Interview

I wanted the students to talk about their work and reflect on how they used their GC. For that reason that I used a stimulated recall technique three times during my data collection phase. I observed a lesson, collected key-stroke data, reviewed the data and then later that same day met with the student and offered them the opportunity to talk through their use of their GC.

Calderhead (1981) suggests stimulated recall is most suited to a naturalistic setting and writes

> *"...it generally involves the replay of videotape or audiotape of a teacher's lesson in order to stimulate a commentary upon the teacher's thought processes at the time."* (p.211)

While Lyle (2003) describes stimulated recall as

> "... an introspection procedure in which (normally) videotaped passages of behaviour are replayed to individuals to stimulate recall of their concurrent cognitive activity." *(p.861)*

The transcriptions of the video-tapes provided clues for the participants and allowed them to 'relive' the situation and describe their thoughts and feelings at that time and allow the opportunity to describe their reasons behind a specific activity.

I used this technique, not with a video-tape, but by using the Key Recorder on a GC to run through the keystrokes made by the student. After an observed lesson I collected the Key Recorder data from the students' GCs and loaded it onto a PC for storage. I then played back each Key Recorder file to ascertain how the student had used their GC during the lesson. Approximately one hour after the end of the lesson I conducted a stimulated recall interview with the students, replaying for them their own Key Recorder file showing them a replay of their use of the GC at least once.

My intention for using this technique was that it would provide an opportunity for the students to explain what they were doing with their GC and their thoughts and decisions when using it. Calderhead (op.cit) writes that this is sometimes referred to as 'protocol analysis' and is

> "*...used in contexts where the participants are not involved in interaction with others. In this procedure, participants are instructed to provide running commentaries or to verbalise their thoughts while engaged in skilled behaviour.*" (p.212)

The students in my project were asked to comment on how they had used their GC during the lesson and identify any use or part of the playback that they felt was significant to them. There are many drawbacks to using this method and Lyle (2003) summarises them as:

- there may be some level of subject anxiety
- the visual aid may not be from the subject's perspective
- whether tacit knowledge can be verbalised
- conscious censoring of the recall by the subject

Calderhead (1981) describes three essential considerations when using stimulated recall interviews: the researcher needs to build a rapport with the subject; the subject must be familiar with the technique; the research goal should be 'screened' from the subject. Lyle (2003, p.864) refers to one shortcoming of stimulated recall as described by Yinger (1986) as when subjects were taking the opportunity to reflect on their reasons for their action as they were viewing the video-tape. It is the reflection by the subject that may lead to analysis on their part and who may then create

> "*... 'explanations' (*a priori *theories) about links between prompted action and intentions.*" (p.865)

Some of these drawbacks became apparent during my data collection. Although the students all volunteered to take part in my project I felt that initially that I was perceived as a teacher-figure and the students were reluctant to speak openly and freely about their work and decisions they made concerning the use of their GC. I found that it took some months before they become more at ease with my presence and the line of questioning although there were some students who seemed unwilling, or unable, to reflect on their own actions during the course of my data collection. The students were not familiar with the procedure and were reluctant to outline their thoughts and feelings about their use of the GC. This was also compounded by some technical issues – the data files replay extremely fast, allowing limited opportunity to see which key-strokes the user was pressing. This made it incredibly difficult for the students to remember and reflect on their use of the GC during the lesson.

The alternative method of playback was to view the list of keystrokes but this too was problematic as this was a view that the student was not used to and was extremely different from the screens that they had seen previously. It was unlikely to enable the student to 'relive' the situation. Although I persevered with this technique, it became obvious that the students were not able, through technical difficulties, lack of familiarity with the display and limited rapport with me to comfortably report on their thoughts, actions and decisions while using their GC. I eventually decided to tack a different approach and replay the file for myself and examine the keystrokes made by the student, replay the data for them and allow them to highlight any issues they felt were pertinent and following that have a general discussion with the student about their use during the lesson in question.

Calderhead (1981) states that stimulated recall, or protocol analysis, cannot provide a complete account of the subject's thoughts and it is unlikely to be of use on its own. This is why I chose to combine a classroom observation, key-stroke data and this stimulated recall technique for interviewing to provide the opportunity to acquire a more in-depth understanding of how the students use their GCs and why.

5.3.5 Students' GC Journals

I asked the students to act as researchers with the intention of each emailing their thoughts to me as and when they used their GCs, writing almost as a diary or journal. As an alternative, the students could complete a journal with their thoughts during the times when they are using ICT and hand this to me at our next meeting. Using journal or diary entries as a data collection method places a great deal of responsibility on the students and relies very heavily on their goodwill. Robson (2002) suggests that even though at first diaries appear to provide data on situations that would be difficult to observe there are factors that may distort the content of the diary. He writes that the author may have a desire to please the researcher and potentially misreport their behaviour or even change the behaviour being reported so that it shows them in a positive light. Bryman (2001) outlines some disadvantages of using diaries as the diarists are likely to reduce the number of entries as time progresses and if there is too much time between an activity or event and write in the diary entry then it is likely that memory recall problems may set in. However journal entries can often provide information about the diarist through writing that they would otherwise not divulge (Bryman, 2001).

During the data collection period the students were reluctant to provide journal entries. At one of the schools all three students emailed me journal entries from time to time but at the other school none of the three students chose to email their entries, instead they handwrote or related verbally their thoughts and opinions. In total I received 29 journal entries which provide a mean of 5.8 entries per student and a range of 2 entries to 11 entries per student.

In retrospect, the journals did not meet their full potential as the amount of guidance given to the students was very limited. Corti (1993), as referred to by Bryman (2001), describes providing guidelines for the diarists detailing what they should include in their entries; a model of a completed entry; time periods within which behaviour and activity is to be recorded; checklists to act as a memory aid.

Although the two groups of students I followed made relatively few journal entries, the data provided by this method affords the opportunity for another perspective on their activity, behaviour and opinions.

5.4 Data Analysis

Lincoln and Guba (1985) write that naturalistic inquiry should develop over time, with constant reviewing of methods used and data produced. They promote inductive data analysis i.e. grounded theory (ibid. p.203). Although I did not implement grounded theory for my study I decided to incorporate a grounded approach to the data analysis phase. I analysed the data based on the measures devised to inform my research questions and research areas but prior to that I adopted a grounded approach to allow themes to emerge from the data during analysis.

I began the initial stage of my data analysis phase by immersing myself in the data from one student by reading the field notes and transcripts from the interviews as well as reviewing the observations, journal entries and the key-stroke files. Considering all the different data sources and placing them in chronological order, I took each and noted down the emergent themes and began to categorise these themes and develop a coding scheme.

As I analysed one student's data and I found instances of a specific code, I noted down the context and which data source it came from and the page number if necessary. Table 5.3 is an example of my record keeping and coding for Sarah exploring features of her GC. I then took my coding scheme and applied it to the data from each of the remaining five students. There was some further refining of the coding scheme and at this stage I reviewed all the data again and applied the latest version of my scheme. The next stage was to merge some of the categories together and develop links between some of the categories and try to develop some depth and dimension to them.

The data analysis using the measures previously set out began after I had completed the grounded approach to the data. Data from all sources was used to address and inform all three of my research areas. All the data sources were used to ensure validity of the research questions and the hypothesis previously stated. I took each piece of evidence in turn and read and re-read it again before attempting to match up the measures with the data. I used a recording sheet similar to Table 5.3.

Using instruction book. Reading manual – seeing potential of GC Graphs & Radians to degrees in science Play on GC when teacher 'babbling'	Interview1 p.1
Using instruction book to create polar roses	Student Journal 2
Storing numbers in variables and using these with quadratic formula – not the example from the book	Key Recorder1 p4
Trying unsuccessfully to save quadratic formula as program	KeyRecorder1 p5
Now know how to use fractions	Student Journal 4
Exploring menus on GC	Key Recorder2 p3
Drawing polar rose and polar stars Storing graphs	Key Recorder2 p4-5 p.6
Solving quadratics - long way not using GC to full. Did use GC to solve quadratics in beginning. Forgotten that it could do this?	Observation & Stim. Recall2 p.2-5
Teachers only focus on one button at a time Not really looked at instruction book (contradiction)	Interview3 p.3
Brief look at manual. Will look at manual more in A2. Polar roses	Interview3 p.4

Table 5.3 Example of Initial Recording System

When I had reviewed all the data for all the students using this approach I collated all the data recording sheets for a particular measure and begun to interpret the evidence.

5.5 Logistics

This section describes some of the logistical problems I encountered while conducting my data collection at the two schools.

The schools, Heads of Department and teachers at the schools I visited were very supportive and provided access to the students who volunteered for my project. However, as in all schools there were instances when the timetabled lessons were altered and as I was not a member of staff, I was not informed. On several occasions I arrived at school for a data collection session only to find the school closed for a training day or the year 12 students were required by the school photographer. There were also several occasions when the teacher was absent and the lesson was being covered by another teacher. In each of these instances I attempted to reschedule my data collection but there were two classroom observations that could not be rescheduled and were deleted from my overall data collection schedule.

The Heads of the Mathematics department were very generous in finding me quiet rooms to meet with the volunteer students for interviews and key-stroke data collection and stimulated recall sessions. Unfortunately there were several instances where quiet rooms were unavailable and the interviews or discussions with the students were conducted in front of other students or members of staff. While this was not ideal, at that time there were no alternatives available and I deemed it better to have an interview under those circumstances rather than no interview at all.

Each of the two groups of students had two mathematics teachers for their AS Level Mathematics. The teachers from school A both said that they did not teach the students to use their GC or teach the mathematics using the GC but it was there if the students wanted to use them. In school B the teachers said that they did support the students when using their GC and did some teaching of the AS Level Mathematics using the GC. However it became apparent that one of the teachers from school A began changing his usual classroom practice due to my presence in the school and in his class. At the beginning of the year he appeared to make some small moves to integrate the GC into his teaching scheme, however this did not endure for the whole year and eventually the teacher seemed to settle back into his regular teaching practice.

I expected the students to be wary of me and initially this did seem to be the case. Although I attempted to build a rapport with the students I felt that even by the end of the year there were still two of the students who were very careful with what they said to me and seemed to try and tell me what they thought I wanted to hear. The remaining four students appeared to be at ease when talking with me and hopefully felt comfortable enough to be able to express their opinions freely without feeling unnecessarily awkward. I was concerned that the students may have been anxious, being involved in data capture methods that may be unfamiliar to them, for example hierarchical focussing and stimulated recall interviews. I considered that one or more students may not have been asked their opinions on this topic before or maybe they were unable to verbalise their understanding or lack of understanding of the mathematics or their use of the GC.

As the research study was conducted by just one researcher it is not possible to determine the reliability of the study, because there is no way to assess the level of researcher bias. There are opportunities for researcher bias within data collection (observation of students) and data analysis (coding of the interview transcripts or interpretation of the findings). Robson (2002, p.324) outlines some observational biases as:

- selective attention: interests, experience and expectations all affect what we pay attention to. It is possible that all six students and I could have our attention affected by these factors.
- selective encoding: being quick to judge and interpret situations before all the data have been collected and reviewed.
- selective memory: time between collecting the evidence and processing it will be less accurate and incomplete.
- interpersonal factors: the students being affected by my presence or more widely, their participation in my project.

The Key Recorder software requires an extended memory within a GC and so is only available on TI-83+ or models with similar memory size. All the AS Level Mathematics students were asked to buy a GC by their Mathematics department but the calculators being recommended by the schools were either not compatible with the Key Recorder software or the memory size was insufficient. The students at school A were asked to buy a Sharp EL9450 and those at school B were asked to buy a TI-82 GC. To overcome this difficulty I supplied the students with TI-83+ GCs. The six students who volunteered had rarely used a GC previously if at all, so therefore the students at the beginning of the year were not familiar with any particular make or model of GC. However the students in school B had a slight advantage over the students from school A because they were using the same make GC as the other students in their class except it was a different model although there were features that were common to both models of GC. The students in school A used completely different GCs from their classmates and at times struggled with identifying some of the features and functions of their GCs that were being explained by their teacher or fellow class members.

5.6 Privacy and Confidentiality

Prior to my asking for volunteers at each of the two schools I confirmed that all the data collected from the volunteers would remain private and confidential. I also assured all the potential volunteers that during any reporting of my work the students who participated in my study were guaranteed anonymity and confidentiality at all times. I outlined all the types of data I would be collecting and reiterated that their views and opinions were confidential and at no time would I relate this information to the school or to their teachers.

All the names of the students within this thesis have been altered to maintain this level of anonymity and confidentiality.

5.7 Reliability and Validity

The data collection period lasted 10 months and five different types of data were collected during this time. I anticipated that the data from one particular data collection tool would be consistent with the data from the same method of collection but at a different time of the year and therefore go some way to ensure the reliability of my findings. The variety of data collection methods I used provided not only the quantity of data I required but also enabled comparisons to be made between students and between schools. If the findings from one data source corroborate the findings from another it can attribute some validity to my results.

The evidence collected was consistent through the passage of time and also between the different methods employed. My main concern was that during interview or student journal entries one of the students in particular seemed to contradict himself when describing the way in which he used his GC. His actions seemed to contradict his verbal account. I interpreted this as the student (Sam) anticipating what he thought I wanted to hear and he attempted to adopt this view when in interview or when he wrote his GC journal entries. During analysis I decided not to rely on Sam's verbal account alone but compare it with the Key Recorder data he generated.

Chapter 6 – Key Recorder

Key Recorder is a software program that was developed as a research tool by Texas Instruments in conjunction with Plymouth University and which records key-strokes made on a GC. It is a relatively uncommon data collection tool and after analysing the available literature it appears that there are only a small number of research projects that have used it. (For example: Graham, Headlam, Honey, Sharp and Smith, 2003; Berry, Graham and Smith, 2003; Smith, 2003; Berry, Graham and Smith, 2005; Berry, Graham and Smith, 2006). Within this chapter I outline the merits, drawbacks as well as my experiences of using Key Recorder. It is a brief summary as I have written about it elsewhere (Sheryn, 2005; 2006).

6.1 Background to Key Recorder

The Key Recorder program is stored in a GC as an Application file (APPS) and runs in the background recording all the user's key-strokes. The Key Recorder requires an extended memory to run and store the data files and therefore it can only operate on the TI-83+ family of GCs which have the increased memory capacity. When Key Recorder is running and collecting data the GC operates as per normal and at the same speed, and therefore there is little indication to the student that key-strokes are being recorded. At the end of the data collection period it is then possible to playback the data file and observe how the student used their GC.

The software program can be loaded onto a GC from a PC with the use of TI-Connect[7]; alternatively it can be transferred from GC to GC using a link cable and the LINK feature on the GC. Unfortunately it is not possible to access the Key Recorder program to either view or edit the code. The data files containing the key-stroke information are stored as Application Variables (AppVar) files with a default name of AkyRecd.8xv. These files can be transferred from one GC to another, although each GC can only store one file at a time, or alternatively the data files can be transferred to a PC and given a more meaningful name other than the default name. However the files cannot be changed or converted to a different file type which means that during analysis the only way to access and view the data file is through Key Recorder run on either a GC or through a relatively recent software release from Texas Instruments called TI-SmartView[8] running on a PC. See section 6.4 for further information.

Weigand and Weller (2001) investigated student working styles while using computer algebra systems. As part of their data collection procedure they used a program, ScreenCam, which recorded all the student's actions on the CAS. The program was running in the background

[7] TI-Connect can be found from the Texas Instruments web-site at education.ti.com/educationportal/sites/US/productDetail/us_ti_connect.html (last checked 27th March 2006)

[8] TI-SmartView can be found from the Texas Instruments web-site at education.ti.com/educationportal/sites/US/productDetail/us_smartview.html (last checked 27th March 2006)

while the students worked on the computer-based CAS. Weigand and Weller used ScreenCam because it meant they were able to quantitatively evaluate the students' computer actions, it also made it possible to identify successful problem solving strategies and dead-end strategies. In their summary they say that

> *"... computer protocols are a useful research tool for studying working styles of students as they go about solving problems, and for categorising problem solving strategies."* (p.109)

The Key Recorder software has similar principles to the ScreenCam program.

Smith (2003) conducted a study also using the TI-83+ and the Key Recorder software. His initial method of analysing the data collected involved transcribing all the key-strokes a student had made onto a data collection sheet. This was found to be very time-consuming and the method was modified so the data screen was videoed and during playback comments were dictated into a tape recorder and 'key events' identified – for example entering a function, changing window settings, graphing a function or using the zoom function.

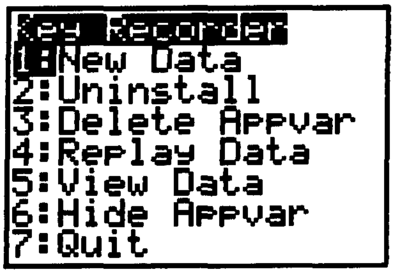


Figure 6.1 Key Recorder Main Menu

The data file produced can be viewed in two ways: View Data and Replay Data.

<u>View Data</u> which provides a list of the keystrokes (Figure 6.2)

<u>Replay Data</u> which plays back the data file and will show the display that the user saw while they were operating it. (Figure 6.3)

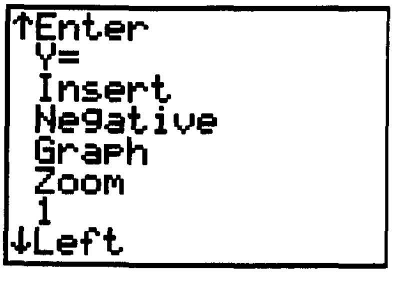


Figure 6.2 Example of View Data Screen

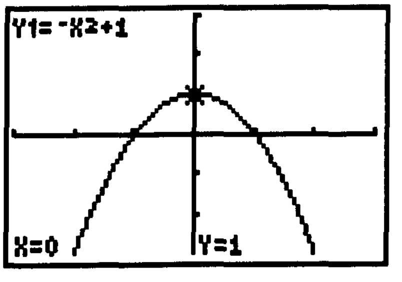


Figure 6.3 Example of Replay Data Screen

6.2 Advantages

Key Recorder provides an exact account of how the GC is being used by storing a list of all the key-strokes made by a user. The data can be used in many ways: to identify how a student's use of the GC changes over a period of time; what problem solving strategies the student adopted;

the frequency and type of errors created; navigation issues; how the student used the GC in comparison with how they were taught; how they use it outside the mathematics classroom.

The Replay Data file will show all error messages (for example ERR: DIVIDE BY 0 or ERR: NONREAL ANS) and from this it is possible to identify any recurring errors made by the student and their frequency. The View Data file will not indicate when the GC produced an error message or if the student arrived at an incorrect answer, but if it is considered in conjunction with the text-book or worksheet from which the student was working, it is possible to identify any repeated errors when entering data. For example: given sin^2*x* or sin*x*^2 on their own it is not clear which one the student meant to enter but if the original worksheet is referred to it is possible to determine which the student meant to enter. The View Data file may also indicate if the student is experiencing GC navigation problems. If a student is looking for a function of the GC but cannot remember which menu leads to this function the student may go searching by pressing a variety of keys in an attempt to find it.

The Key Recorder files also provide the opportunity to see if the students are using it in the way they were taught. If the student found alternative methods to those being taught by the teacher or if they are teaching themselves to problem-solve using alternative strategies. Analysing the key-stroke data and comparing it to the AS Level Mathematics syllabus also indicates if the student has used the GC in unexpected or independent ways to investigate areas of mathematics that are not on their syllabus.

Key Recorder also offers the possibility of identifying how a student uses the GC outside of a mathematics classroom. Students within my project were asked to enter an alpha code into their GC before using it. A different alpha code was to be used depending on the type of use or location. This was in an attempt to identify their work at different times and in different situations: work in the mathematics classroom; within other AS Level classes; at home or outside formal classes. Although this was not totally successful throughout the year it did provide some indication of how the students used their GC outside of the mathematics classroom.

6.3 Disadvantages

There are quite a few disadvantages to using Key Recorder software and data files. As mentioned above there are two ways to view the data – Replay Data and View Data. During playback the Replay Data mode will show what the user saw on the display as they worked with the GC. However during replay it will display the whole data file all at once, quite quickly, and it offers no opportunity to pause the replay or to jump towards the end of the file, although it is possible to halt it – by pressing the ON key. Viewing the Key Recorder data through View Data screen indicates exactly which keystrokes the user pressed but the display only shows eight lines of data at a time. The file can be scrolled through using the arrow keys but for larger data files (over 1000 key-strokes) this can be a laborious process. Unfortunately it is not possible to skip from one section of the file to another which means if the end of the file is being analysed the whole file must be scrolled through one line at a time.

If a student runs an application program on the GC (for example the Probability Simulator) while the Key Recorder is collecting data during analysis the playback will halt at this point and the program will begin to run. It is possible to see the key-strokes that have been made after this point but the playback must be changed to View Data. Playback will also stop when the maximum file size is reached. The default is 1000 key-strokes although it is possible to change this. Frequently I over-estimated the size of the data file needed to collect the data knowing there was more than enough space to store the data.

During periods when data collection exceeded one lesson, it is likely that the student will have turned the GC off or it will have 'timed out'. Neither of these situations can be identified by examining the key-strokes as Key Recorder does not record when ON or OFF key has been pressed. While this is understandable – during playback the Key Recorder would turn the GC off and therefore not be able to continue playback – it would help the analysing process if there was an indication whenever the student switched off the GC or it 'timed out'.

If a student allows the GC to 'time out' while they are in a screen other than the HOME screen and then switches it on the GC will continue from where it was before it 'timed out'. However, if a student switches the GC off and then later switches it on the GC will automatically display the HOME screen. The Key Recorder software will not record that the GC has been switched off but will continue playback in the mode that the student had been previously working. While this is not a problem for the student, this can cause significant confusion with playback and analysis of the data and it could produce errors during playback that the student will not have experienced. For example: a student enters an equation to be graphed through Y= editor and then turns the GC off. When they return to work with the GC and turn it on they will have the HOME screen to work with. During playback the display will not register that the GC was turned off/on but it will continue all playback within the Y= editor.

Another disadvantage is that it is not possible to determine if all the key-strokes recorded on the GC are from one student or two or more. During the course of my project it became evident that one student was sharing her GC with her neighbour in class. She explained how often she was sharing her GC and who with but it transpired she was also allowing others to borrow her GC from time to time. The analysis of data then becomes much more complex and potentially confusing.

6.4 TI SmartView – a GC Emulator

Those who are familiar with a relatively new software release from Texas Instruments called TI-SmartView may think that these disadvantages may be overcome using this piece of software.

TI-SmartView is an interactive representation of the TI-84+ (similar to the TI-83+) that can simultaneously display multiple representations of Graph Window, Table, Statistics Editor and Y= Editor screens on a PC. It can also record and show all the key-strokes of the user. The data can be collected from TI-SmartView and stored on the computer but it is not possible to collect data from a hand-held TI-84+ (or similar) and transfer it to TI-SmartView. However Key Recorder can be installed onto TI-SmartView as an application and the data files from elsewhere can be transferred into and run using TI-SmartView. Although playback is still very fast the advantage is that it does cut down on time spent transferring files to and from the GC and PC.

6.5 Analysing Key Recorder Data

This process was not straightforward and was an extremely protracted exercise. Initially I replayed the data through Replay Data to understand the general area of mathematics that each student was working on, making note of any areas of interest. I then played the data file back as View Data and recorded each of the keystrokes made. Once I had done this I could note down the type of activities on which the student was working. (Figure 6.4) This was an extremely lengthy process but enabled me to have an overview of the student's working followed by a detailed report of their GC activity. From this point I was able to analyse the student's key-strokes along side the interviews and observations and identify themes from the data.

6.6 Key Recorder Summary

As a data collection tool, the Key Recorder software is very labour intensive. It can produce vast amounts of data but unfortunately the only way to successfully analyse the data is very tedious and can only be done through a GC or a GC emulator (TI-SmartView).

Although when Smith (2003) analysed the data from his research project he videoed the playback, for extended data collection periods this method is not always successful for the reasons described above. Problems can arise that meant the playback is interrupted or it may produce an error not experienced by the student. This can mean vital elements of the student's use of the GC or key-strokes are not captured by the video. To avoid this situation I worked through each list of keystrokes manually – identifying key areas and then working through their key-strokes analysing the processes and the key-strokes used.

The Key Recorder was a useful data collection tool, allowing access to students' work in and out of the classroom and it provided details of how the students used their GCs that otherwise would not have been possible. Collecting key-stroke data enabled me to see how the students' use of their GCs changed over the course of the year as they became more familiar with the GC and found where different functions were and how to navigate around both the screen and the GC successfully.

Key-stroke	Comment
A	4.9 stored in A
Left	
4.9	
Store	
A	
Enter	
Negative	-10 stored in B
10	
Store B	
Enter	
10	1 stored in C With a mis-type of DRAW
Left	
Del	
Store	
Draw	
Clear	
C	
Enter	
Negative	$-B+\surd(B^2 - (4AC)) \div (2A)$ Using previous stored values in A, B and C = 10.91495966
B	
Plus	
Left Parenth	
Left	
Del	
Square Root	
B	
Squared	
Minus	
Left Parenth	
4AC	
Right Parenth	
Right Parenth	
Exponent	
Left	
Del	
Divide	
Left Parenth	
2A	
Right Parenth	
Enter	
Entry	Alters previous entry $-B-(\surd(B^2 - (4AC)) \div (2A)$ {Incorrect calculation – should use minus and NOT negative, but also requires further brackets. Answer should be 46.46818154}
Up	
Left	
Negative	
Enter	

Figure 6.4 Example of Key Recorder Data Sheet

There are many problems associated with Key Recorder and although the disadvantages do appear to outweigh the advantages, the software does provide some unique opportunities for gauging an insight into how an individual uses their GC. It is for this reason I felt able to work around the disadvantages and focus on the advantages of collecting this type of data.

Chapter 7 – Results

This chapter includes the results from the data collected from the six students over the course of the academic year 2003-2004. The results are split into two main areas: Measures Informing the Research Questions and Emergent Themes. I chose to make separate sections for these as the results are generated from two separate and distinct approaches. Measures informing the Research Questions arose from the measures set out in Chapter 3 Research Questions. The research questions and measures were developed before any data collection began and can be considered as *a priori* thinking. Emergent Themes were themes generated from examining the students' data which can be considered as *a posteriori* thinking. I read through the files of data from each student and then developed the categories from what I saw as significant elements of the data. The Emergent Themes are in addition to the Research Questions. They are included as they offer an alternative picture of the students' appropriation of their GCs.

Due to space restrictions the results included below are a reduced and abbreviated set but include all the data that I refer to later.

7.1 Measures Informing the Research Questions

The three research areas that I am addressing break down into five research questions. Each research question has several measures associated with it and each measure relates to different aspects of a student's use of a GC. In section 2.4 Framing of Research Questions (p.9) I outline which data sources inform which measures that in turn inform the research questions. In this section I detail how the data collected corresponds with these measures and ascribe a variety of data sources to each measure. I worked through all the data sources for all the six students and I took each data source in turn assigning measures where appropriate.

The abbreviations I use within this section are as follows:

Int	Interview
KeyR	Key Recorder data
Jrnl	Journal entry
Obs	Classroom observation. Key Recorder data files were also collected
ObsKR	Key Recorder data files from lesson that was also observed
ObsStR	Classroom observation, followed by a Stimulated Recall interview. Key Recorder data files were also collected
ObStRKR	Key Recorder data files from classroom observation that was followed by Stimulated Recall interview
StRcl	Stimulated Recall interview using Key Recorder data files taken from an observed lesson

Table 7.1 Abbreviations of Data Sources

The page number follows the data source. For example *ObsStR3 p2* in the data source column below corresponds to page two of the third Classroom Observation followed by a Stimulated

Recall Interview. Table 5.1 Actual Schedule of Data Collection (p.29) indicates when in the year the data were collected.

The results based on the measures from my Research Areas are shown below for each student in alphabetical order – Ann, David, Max, Sam, Sarah, Steve.

7.1.1 Ann – (School A)

The quantity of evidence collected for Ann is slightly less than from the other students from school A due to her absences from class during various data collection sessions. Her teachers were concerned about her level of attendance from the middle of the first term and were expecting her to withdraw from the AS Level Mathematics course early. Ann did complete the course but unfortunately she was absent for several data collection sessions including the summary interview. Although the data collected from Ann are incomplete compared to other students in my study, her data can provide some comparisons with other students within her school.

Measures from Research Area 1	**Data Sources**
1a) Extent of use of a scientific calculator	
Will replace scientific calculator with GC in future but will have to get used to it first	Int1 p1
Very limited use of GC over a two week period	KeyR1
Still used to the scientific calculator– clearing screen after each calculation	StRcl1 p1
Still uses scientific calculator 'sometimes' – "*depends on what my needs are*". Still carrying the scientific calculator to school.	Int2 p2

1b) Student's responses to teacher's prompts to use GC	
Finds it useful to check answers – corresponds to the teacher's view	Int1 p2
Follows the teacher's prompts to resize graph window	KeyR1
Mentions writing messages to her neighbours on the GC	StRcl1 p4

1c) Evidence of unexpected use	
None	

1d) Use of GC out of class	
Uses the GC more in class than for homework Does not think the GC will be useful in Biology or Psychology	Int1 p1 Int1 p3
No evidence of the GC being used outside the mathematics class	KeyR1
Did not know how to change radians to degrees & the teacher did not know either. Found out by investigating for herself	StRcl1 p4 Jrnl1
No evidence of use of GC outside class	KeyR2
Used the GC for homework	KeyR3 p9
No evidence of use of GC outside class	KeyR4

1e) Extent of use of GC	
Only used the GC in lessons during the 1st week. Had not used a GC before Was going to use the scientific calculator & GC together until she was used to GC Checked her work with the GC. Had not used the GC a lot so far Does not think the GC will be useful in Biology or Psychology	Int1 p1 Int1 p2 Int1 p3
Very limited use of the GC over the two week data collection period.	KeyR1
Still used to the scientific calculator & is clearing screen after each	StRcl1 p1

calculation	
Very limited use of the GC over a 2 week period.	KeyR2
Very limited use of the GC due to examination. Used it more at the beginning but now using it less and less. Usually uses the GC every lesson. States that she did not use the special features of the GC just the 'normal' things.	Int2 p1
Used the GC for homework.	KeyR3 p9

1f) Different subject areas where the GC is used	
Drew graphs to check solutions to equation. Thinks she would not need the GC for any other subjects. Checks her work with the GC	Int1 p1 Int1 p2
Solving quadratic graphs	KeyR1
Trigonometry – degrees	ObsStR1 p1
Trigonometry – degrees; integrals, calculus and straight line theory	Jrnl1
Drawing graphs and checking answers Trigonometry	Int2 p1 p2
Statistics Binomial	KeyR3 p4 p24
Numerical Integration	Obs2 2
Graphs, combinations, permutations, binomial sequences and integration	Jrnl2
Combinations	ObSRK2 p2

1g) Frequency of use of GC with respect to other instruments	
Using the scientific calculator & the GC together until confident with GC	Int1 p1

1h) Evidence of a student's succinct use of a GC with few errors	
Persistent navigational issues throughout session. Having trouble moving around screen and deleting characters ERR:SYNTAX – lack of understanding of how to move around screen QUIT	ObsStR1 p2, 3, 5, 6, 7, 8 p2,6
7^$^{-2}$ ERR: SYNTAX. Lack of understanding how to quit or clear error – trying to treat GC like WP Lack of understanding how to delete characters. Incorrect attempt at Arcsine ERR: SYNTAX QUIT Lack of understanding how to move around screen. Incorrect attempt at Arcsine ERR:SYNTAX not sure how to clear error	KeyR2 p1 p2, 3 p4 p5
√-ve no. = ERR:NONREAL ANS clear error Entering STAT screen (in error) and trying to return to HOME screen Multiple screen clearing ERR: UNDEFINED after deleting all data from lists. Clear error x 3 0- = ERR: SYTNAX. Quit error √(= ERR:SYNTAX clear error -8 –4 + 12 – 14 = ERR:SYNTAX clear error Trying to return to HOME screen from y = editor	KeyR3 p4 p5 p7 p8 p17 p19 p23
$y = 0.5x$ + ERR :SYNTAX quit error ANS + = ERR :SYNTAX clear error. Trying to delete previous entry FnInt($.5x + 2)^2$ = ERR:ARGUMENT clear error	ObsKR2 p1 p2 p3
Trying to find Numerical Integration on GC. 20 ÷ √(77 x 0) = ERR:DIVIDE BY 0 clear error + × = ERR:SYNTAX clear error	KeyR4 p1+ p7 p8
. = ERR:SYNTAX clear error 4! × 4! × = ERR:SYTNAX clear error	ObsStRKr2 p1 p2

1i) Apposite use of the GC	
Drawing graphs and resizing the window	KeyR1
Trying to find Numerical Integration on GC.	KeyR4 p1+

Measures from Research Area 2	Data Sources
2a) Comments from students on the advantages or perceived potential of using a GC	
Useful for checking solutions to equations. Useful for checking work Will be useful for AS and A2 work – more functions. Teacher said it was an advantage to have one. Told to get GC – not sure what it's benefits may be	Int1 p1 Int1 p2
ENTRY feature useful. Becoming more useful the more she uses it GC useful for drawing graphs and ALPHA keys for writing messages. Not sure what ALPHA keys may be used for	StRcl1 p3 p4
GC as checker. Lots more useful functions than scientific calculator	Jrnl1
Was not very different to scientific calculator. Do not use special features just "*normal*" things. Would have liked to use GC in examination. GC just handier. Lots more different functions. Would rather have GC than scientific calculator	Int2 p1 p2
GC is quick, clever and efficient. A lot easier than scientific calculator. Seeing what you typed in earlier is good and changing calculation by using ANS or ENTRY	Jrnl2

2b) Comments from the student on disadvantages or perceived constraints when using a GC	
Perceived problem finding buttons Need to learn and practice where all buttons etc are	Int1 p1 Int1 p2
Knowing which button to press can be "*a bit confusing* "	Int2 p3
Hard to work out new things when teacher unaware of processes on GC	Jrnl2
Slow process finding factorial or permutations or combinations	Jrnl2

2c) Comments from students about the level of support or training needed	
Did not know how to change radians to degrees & neither did teacher	StRcl1 p4
Not able to use GC for numerical integration. Teacher gave support to those students with Sharp GC	Obs2 p2
Searching for integration tool	ObsKr2 p1
Hard to work out new things when teacher unaware of processes on GC	Jrnl2

2d) Comments from students about the level of support or training received	
Did not know how to change radians to degrees – teacher did not know. Found out by investigating for self	StRcl1 p4
Not able to use GC for numerical integration. Teacher gave support to those students with Sharp GC	Obs2 p2
Searching for integration tool	ObsKr2 p1
Hard to work out new things when teacher unaware of processes on GC	Jrnl2

2e) Types of difficulties faced when using GC	
Learning where all buttons and functions are and what they do and when you need them	Int1 p2
Continued navigational issues throughout session. Trouble moving around screen and deleting characters Frustration at not being able to delete as would like – multiple keystrokes	ObsStR1 p2, 3, 5, 6, 7, 8 p8
Difficulty finding correct keys	StRcl1 p3
Difficulty finding how to change radians to degrees	Jrnl1
Poor recovery from error – trying to treat GC like WP Lack of understanding how to delete. Lack of understanding how to move around screen Not sure how to clear error	KeyR2 p1-3 p4 p5

Knowing which button to press	Int2 p3
Entering STATS screen (in error) and trying to return to HOME screen Problems deleting items from STATS editor. ERR:UNDEFINED after deleting all data from lists Trying to return to HOME screen from Y = editor	KeyR3 p4 p6 p23
Not familiar with numerical integration on GC	Obs2 p2
Searching for integration tool	ObsKR2 p1
Slow process finding factorial or permutations or combinations	Jrnl2
Trying to find Numerical Integration on GC.	KeyR4
Trying to alter previous entry. = ERR:SYNTAX clear error	ObsStRKR2 p1

2f) Success in using a GC for problem-solving	
Missed opportunity to use ENTRY but using ANS Used ANS	ObStR1 p4,8 P5, 6
Checking last 4 answers using ENTRY	KeyR2 p2

2g) Changes in a student's level of confidence when using a GC	
Initially she did not want to mess around with GC. Using scientific calculator and GC together until confident using GC. Have not used GC a lot – would give it 2.5 / 5 for usefulness. Concerned whether she will remember where all functions are and what all buttons do. Told to get GC by teacher – not sure what it's benefits may be	Int1 p1 Int1 p2
Multiple CLEAR after error More than 8 attempts at same calculation. Lack of confidence in GC. Checking and re-checking answer to same calculation	KeyR2 p1 p1-3
Confident use of ANS Multiple CLEAR screen. Repeated screen clear after every calculation Checking answer by breaking calculation down into parts	KeyR3 p11 p11 + p18
Multiple CLEAR screen × 4 twice	ObsKR2 p4
Increased number of Clear screen as data collection progresses Confident use of ANS. CLEAR screen more than 3 times after each completed calculation	KeyR4 P4, 10 – 14
Confident use of ENTRY Multiple CLEAR screen x 4; confident use of nCr Multiple screen CLEAR x 9	ObStRK2 p2 p3 p4

7.1.2 David – (School B)

David was a reluctant volunteer for the project. He only volunteered when he realised that his friend, Steve, was also taking part in the study. His attendance was very good during the year and he was keen to participate in classroom discussions, however at times David was distracted from working by his neighbours in class.

Measures from Research Area 1	**Data Sources**
1a) Extent of use of a scientific calculator	
Have not been carrying scientific calculator around with him	Int1 p2
Using GC in all lessons. Do not use scientific calculator at all – except when doing basic sum and if its there	Int2 p1
Only used scientific calculator for examinations	Int3 p1

1b) Student's responses to teacher's prompts to use GC	
Needed to be prompted to get GC out Keen to use GC and provide answers before prompt. Follows instructions to use GC	Obs1 p1 p2 p3

1c) Evidence of unexpected use	
Playing around and exploring different functions	Int1 p1
Doodling on arrow keys	KeyR1 p11
Doodling on GC	ObsKR1 p1

1d) Use of GC out of class	
Using GC out of mathematics class – in physics Using GC 2 or 3 times a day	Int1 p1 2
Not mathematics or homework use	KeyR1 p5
In physics for coursework	Jrnl1
Physics and chemistry	Jrnl3
Using GC in physics and at home and in class for revision	Int2 p1
Using GC for revision over holidays	Jrnl4
Using GC for homework	Int3 P2

1e) Extent of use of GC	
Using it for every day use. Also in physics Using GC 2 or 3 times a day. Using it more & more as course progresses.	Int1 p1 p2
Not mathematics or homework use	KeyR1 p5
Using GC in every lesson and home for revision	Int2 p1
Using GC for revision over holidays	Jrnl4

1f) Different subject areas where the GC is used	
Physics	Int1p1
Statistics standard form	KeyR1 p1 p11
Physics coursework, refractive indexes, Pearson's PMCC, graphs	Jrnl1
Statistics PPMCC	Jrnl2
Normal distribution	KeyR2 p4
Photo-electric effect – physics, standard form/powers	Jrnl3
Statistics revision and trigonometry, physics and chemistry	Int2 p1
PMCC and linear regression	Jrnl4
Used GC for General Studies; statistics linear regression; modulus; 2 variable statistics; graph functions; absolute	Int3 p2

1g) Frequency of use of GC with respect to other instruments	
Using GC everyday just like scientific calculator Will use it more frequently than now when they get into the course. Have not been carrying scientific calculator around	Int1 p1 p2
Using GC in all lessons and at home with revision. Not carrying scientific calculator at all any more	Int2 p1
Use GC all the time	Int3 p1

1h) Evidence of a student's succinct use of a GC with few errors	
Trying to delete items from list. Lack of understanding about error message ERR: DATA TYPE goto error and trying to recover from error. Lack of understanding about error message. ERR:SYNTAX clear error and trying to recover from error	KeyR1 p4 p9 p12
Sin (= ERR: SYTNAX. Doodling on the screen	OstKR1 p1
ANS- = ERR :SYNTAX clear error. -- = ERR:SYTNAX clear error - – 239 + -2(286) + -393 = ERR:SYNTAX clear error and then trying to alter calculation on screen unsuccessfully ERR: DIVIDE BY 0 – GC off? Unsure of error. ANS = ERR:SYNTAX 3 times, clear error	KeyR2 p4 p5 p7 p8 p9

Bracket missing ERR:SYNTAX clear error and repeat error	p13
Using GC as would use scientific calculator. It's got all the same functions as calculators we've used previously	Int2 p2
Many missed opportunities to use ENTRY and make simple alterations to expression and not completely rewrite Checking answer from previous calculation Not using ENTRY	KeyR3 p5 p7 p8, 12, 14
ANS – 66 + = ERR:SYNTAX clear error 7,6 = ERR:SYNTAX clear error; 7 x 8, + , 7-5 = ERR:SYNTAX clear error	KeyR4 p8 p9
2^4)= ERR:SYNTAX clear error Storing answer to B and not using it	KeyR5 p6 p9
L_3 2^2 = ERR: INVALID DIM. Clear error	OSRKR3 p2

1i) Apposite use of the GC	
Retyping previous calculation – could have used ENTRY	KeyR1 p2, 5
Repeated calculation, keystroke by keystroke √(19.62) not ANS Could have used ENTRY and made one alteration to complex expression Trying to manoeuvre around screen using arrow keys	KeyR2 p2, 5 p16 p20
Using STORE to keep accuracy in question	Jml4
Clear screen after every calculation. Missed opportunity to use ENTRY & make simple alterations to expressions Checking calculation by building up from 3 separate calculations.	KeyR3 p8, p11 p14
Missed opportunity to use ENTRY & make small alteration to expression Checking answers	KeyR4 p3-5 p11
Not using ANS STORE answer to B and did not use it Less frequent clearing screen	KeyR5 p7 p9 P13

Measures from Research Area 2	**Data Sources**
2a) Comments from students on the advantages or perceived potential of using a GC	
GC a lot better than scientific calculator one. More memory and can do more with it. Will be good to check answers with it	Int1 p1
Useful for statistics. Got all same functions and buttons as calculators used previously	Int2 p1 p2
Useful for statistics. Store functions useful	Jml4
Found scientific calculator quite different from GC. Used to think it was complicated but now think it's quite basic Easier to picture graphs, not having to manually plot them; tracing graphs to find coordinates – helpful. 2 variable statistics; graph functions; absolute	Int3 p1 p2

2b) Comments from the student on disadvantages or perceived constraints when using a GC	
GC too big for bag. GC "*throws*" him when it omits preceding zero (.26 instead of 0.26)	Int1 p1 p2
Standard form and powers are a lot different from scientific calculator – takes longer and wastes time	Jml3
Did not need to use any of GC functions in examination. In standard form need to bracket everything, unlike with scientific calculator. In examination did not really need to use any of GC features and functions. Using GC as would scientific calculator. Fraction key not easily found. Would be useful. Power button not what expected	Int2 p1 p2
Forgetting to change from radians to degrees. No sign on screen	Int3 p2

2c) Comments from students about the level of support or training needed	
Did not have to read manual to get started	Int1 p1
Needed help to store answers in variables. Needed help to find fraction key	Obs1 p4
Asked for help about GC changing from Degrees to radians	Jrnl3

2d) Comments from students about the level of support or training received	
Had to search for ABS button – without help Had to find out how to reset it. Never read manual	Int3 p2 p3

2e) Types of difficulties faced when using GC	
GC omits preceding zero which throws him	Int1 p1
Trying to delete items from list. Lack of understanding about error message Pressing wrong key and returning to previous screen or HOME screen ERR:DATA TYPE and having problems recovering from error ERR:SYNTAX and trying to recover from error	KeyR1 p4 p8 p9 p12
Difficulties moving round screen. Trying to move around GC as WP?	ObsKR1 p2,3
Difficulties moving around screen. GC as WP. Trying to alter previous calculation ERR: DIVIDE BY 0. Switched GC off? Unsure of error. Difficulty exiting Y= editor. Switched GC off? Trying to manoeuvre around screen using arrow keys	KeyR2 p7 p8 p24 p25
Standard form & powers are difficult. Needed to add more brackets. (Did not use EE)	Jrnl3
Standard from and brackets problematic. Need brackets for everything. Can be tedious if loads to do Fraction key lot harder to use. Power key not as expected	Int2 p1 p2
Not changing from radians to degrees	Int3 p2

2f) Success in using a GC for problem-solving	
Having problems using GC for standard form and powers – no success in problem solving	Jrnl3
STORE function useful	Jrnl4
Repeating calculation, checking calculation	KeyR4 p2
Clearing screen. Checking previous calculation. Checking previous calculation Clearing screen	OSRKR2 p1 p3 p4
Repetitive calculations – no use of ENTRY or STORE	KeyR5 p11
2 variable statistics on GC	Int3 p2

2g) Changes in a student's level of confidence when using a GC	
Quite easy to use – did not have to read manual to get started. Interested in using it. Will be good to check answers with it	Int1 p1
Repeated use of clear screen Had trouble deleting items from STATS editor, now able to do this correctly Repeatedly clears screen	KeyR1 p3 p6 p10
Quite easy to use but have not used it for much challenging stuff yet	Jrnl1
Finding using it quite easy though has not used it for anything new yet.	Jrnl2
Doodling on the screen Continued use of clearing screen	ObsStRKR1 p1 p2
Continued use of clear screen throughout. Repeated calculation Repeated calculation in full Previous calculation reworked with brackets everywhere Unsure how to manage error message – GC off?	KeyR2 p2 p5 p6 p8

Repeating calculation this time with more brackets – correct answer Confirming calculation by repeating twice – second time with multiplication sign 4(54) + 5(-20) … 4×(54) + 5 × (-20)+ … Then reconfirming answer by breaking calculation in separate parts 4 × 54 = 216, 5 × -20 = -100, … Then clear screen NINE times	p11 p12 p14 p15
Tedious to put brackets in but gives right answers. Familiarised with most of functions needed	Jrnl4
Frequent clearing of screen	KeyR3
Frequent clearing of screen	KeyR4
Clearing screen, Checking calculation by breaking it down Error entering expression. Navigates round screen successfully	ObsStRKR2 p1,3,4 p4
Clear screen often Less frequent clearing screen using answers displayed on screen Checking answers	KeyR5 p2, p4... p3, 14 p6
Repeated calculations – several – shared GC?	ObsStRKR3

7.1.3 Max – (School A)

Max was an eager volunteer to my project. He immediately agreed to take part and expressed an interest in what the project entailed. His attendance over the year was excellent and he worked very hard during most of his classes. Max was a quiet student and seemed to be focussed on his work most of the time.

Measures from Research Area 1	**Data Sources**
1a) Extent of use of a scientific calculator	
Using scientific calculator due to problems finding exponent key Carrying scientific calculator as well as GC – in case of problems. Knows how to use scientific calculator so feels safe with it as back-up	Int1 p1 p2
Using scientific calculator and GC together. Has problems with trig on GC	Jrnl2
Using scientific calculator for trigonometry	ObsStR1 p2
Did not use GC much to start with because it was new. Used scientific calculator for trig. Did not know how to change radians to degrees on GC	Int2 p2
Only used scientific calculator at start of year for things could not do on GC	Int3 p1

1b) Student's responses to teacher's prompts to use GC	
Teacher prompts class to resize graph WINDOW Prompts to use TRACE and confirm solutions Prompts to expand WINDOW	Obs1 p1 p2 p4
Does as teacher suggests and resizes graph WINDOW and TRACE graph efficiently several times during session	ObsKR1 p1
Teacher instructs students to use GC for numerical integration but students have different model of GC than the rest and are unable to do it	ObsKR3 p1
Using GC to compare answers. Used as a checker (as teacher prompted)	Int3 p1

1c) Evidence of unexpected use	
Writing messages to friends	KeyR1 p8
Writing messages to friends	KeyR2 p2
Writing messages to friends	KeyR3 p1

1d) Use of GC out of class	
Using GC for chemistry	Int1 p1&2
Using GC for homework	KeyR1 p1

Using GC for chemistry and homework	Jml2
ZOOM in function self-taught Altering graph window w/o instruction	KeyR2 p4 p10
Experimenting with storing values into variables	Jml5
Resizing graph WINDOW and using TRACE function without keystroke instruction from teacher throughout session	ObsKR1 p1
Using GC for numerical integration – received training	ObsKR4 p1
Learns to STORE values to variables and use the variable in an equation	KeyR6 p8

1e) Extent of use of GC	
Not used GC before Expecting to use it every lesson. Refers to using it to check his mental calculations. Carrying scientific calculator as well as GC in case of problems	Int1 p1 p2
Drawing graphs, finding solutions and the vertex and used TRACE	Jml1
Using GC for homework	KeyR1 p1
Using GC for chemistry and homework but finding scientific calculator easier for trigonometry	Jml2
Using GC every lesson, including exploring how to STORE values	Jml5
Used scientific calculator at start of year when things could not do on GC Used it to compare back as a checker as prompted by the teacher	Int3 p1 p2

1f) Different subject areas where the GC is used	
Using GC in chemistry	Int1 p1, 2
Using GC in chemistry	Jml2
Using GC in trigonometry	KeyR1 p1
Using GC in chemistry and for trigonometry	Jml2
Graphs and transformations of graphs, statistics, numerical integration	Int2 p1
Statistics	KeyR4 p7
Factorial and standard form	Jml4
Binomial theorem	ObsStR2 p1
Logarithms, binomial theorem (!, nCr)	Jml5
Numerical integration	ObsKR3 p1
Integration, volumes of solids, adding up and double check, iteration	Int3 p2, p3

1g) Frequency of use of GC with respect to other instruments	
Carrying both scientific calculator and GC but preferring to use GC unless there is a problem	Int1 p2
Still using scientific calculator when does not understand GC. E.g. Trig	Jml2
Using scientific calculator when GC on desk. Had problems with changing radians to degrees	ObsStR1 p1
Used GC nearly every lesson Used scientific calculator at the start and when having problems with trig	Int2 p1
Only used scientific calculator at start with things could not do on GC Using spreadsheet to draw graph for integration	Int3 p1 p3

1h) Evidence of a student's succinct use of a GC with few errors	
Created ERR: SYNTAX when entering – 4 rather than -4 when resizing graph WINDOW. Ignores it and views graph	ObsKR1 p1, p6
Typing in trigonometric calculation as if on old-style scientific calculator ERR:SYNTAX minus not negative for WINDOW range ignores error Lack of understanding how to move round Y = editor ERR: WINDOW RANGE ignores error and views graph	KeyR1 p2 p5, p6 p11, 12
, $\sin^{-1}(0.7)$ = ERR:SYNTAX clears error	ObsStRKR1 p1
$\mathrm{Cos}^{-1}(30)$ = ERR:DOMAIN clear error ANS + = ERR:SYNTAX GOTO error but then clears error rather than alter it	KeyR2 p8 p13

$Cos^{-1}(270)$ = ERR: DOMAIN goto error. Adds right bracket then quits error. Does not understand error ANS STO→999 ERR: SYNTAX hoping this would store 999 in memory, QUIT error	p15 p17
Unsuccessfully trying to return to HOME screen Turns GC off due to frustration at not being able to return to HOME screen Trying to edit previous entry by going UP and RIGHT – navigational 8 - – 31 = ERR:SYNTAX GOTO and CLEAR error	KeyR3 p1 p2 p3 p5
Trying to use STORE and creates ERR:SYTNAX clear error Trying to move around STATS editor and return to HOME screen Adds L1 as data item in STATS editor ERR:DATA TYPE goto & clear Adds L1 as data item in STATS editor ERR:DATA TYPE goto and alter but creates again and quits error	KeyR4 p7 p7, 8 p9, p10
Not entering standard form correctly. Needs brackets everywhere. 6.84 [× 10^x]-49 should be 6.84[EE]-49. Difference between syntax of GC and syntax of written page.	Jml4
√-ve number ERR:NONREAL ANS quit error twice 5 + 56495875135… - = ERR:SYNTAX clear error	KeyR5 p9 P10
$e^{(-200)}$ ERR:SYNTAX minus not –ve quit error	ObsKR4 p1
25(1 – (5^400)) = ERR: OVERFLOW QUIT error times 3. Does not understand the error message Incomplete set of brackets ANS x 2!) – ERR:SYNTAX clear error Extra bracket ERR:SYTNAX clear error Incomplete expression … + = ERR:SYNTAX goto & fixes error successfully √-ve number = ERR: NONREAL ANS quit error, again, clear error. Does not understand error message	KeyR6 p3 p13 p15 p17 p24

1i) Apposite use of the GC	
Using graph vertex and values of *x* to solve quadratic. Using TRACE to check answers	Jml1
Using WINDOW and TRACE to find vertex and solutions of quadratic graph. Viewing table of values to aid in solving quadratics	ObsKR1 p1 p3
Using WINDOW to alter size and TRACE to find features of graph	KeyR1 p8
Not using standard form feature successfully	Jml4
Not using standard form feature successfully	Jml5
Using GC for numerical integration – received training – rather than relying on manual calculation entirely	ObsKr4 p1
Using [nCr] and factorial to solve binomial theorem Using GC for iteration	Int3 p2 p3
Learns to STORE values to variables names and use the variable in equation	KeyR6 p8

Measures from Research Area 2	**Data Sources**
2a) Comments from students on the advantages or perceived potential of using a GC	
Likes to be able to see previous calculation on screen. Hopes to do graphs and equations on it in the future. Expects GC to be useful when transforming graphs	Int1 p1 p2
Good to see what's happening step by step	Jml2
Useful for transforming graphs Liked being able to review recent calculations, drawing graphs Can view everything on the screen	Int2 p1 p2 p3
Editing previous calculations is useful.	Jml4
Able to see all previous working. Worked with ENTRY. Good for iteration	Int3 p3

2b) Comments from the student on disadvantages or perceived constraints when using a GC	
Little bit complicated to start. Had problems finding exponent key	Int1 p1
Changing WINDOW every time you draw a graph is a nuisance	Jrnl2
Deleting character from input string is not as expected. Not like WP. √ should have own key not [2nd] [x^2]	Jrnl3
Slow to find factorial key on GC. Standard form requires lots of brackets	Jrnl4
Confusing having to bracket everything when using standard form	Jrnl5
Complicated at times	Int3 p2

2c) Comments from students about the level of support or training needed	
Says he needs to read manual to understand differences between scientific calculator and GC	Int1 p1
Needs help with WINDOW function Asks for help with TRACE function Has problem finding fraction key	Obs1 p2 p3 p4
Needs help finding fraction key	ObsKR1 p1
Needed help finding changing radians to degrees Teaching himself about ZOOM standard Prefers to investigate rather than read manual. Asked teacher about changing radians to degrees but unable to help	ObsStRKR1 p2 p3 p4
Needs training to master STORE	Jrnl3
Needed training to master numerical integration	Int2 p1
Needs help INS/DEL and overwriting	KeyR4 p3
Needed to store values but do not know how	Jrnl5
Needed to store values but do not know how	StRcl3 p1

2d) Comments from students about the level of support or training received	
Teacher instructs class to alter WINDOW size Teacher instructs class to use TRACE to confirm solutions	Obs1 p1, 2 p2
No help from teacher about changing radians to degrees	ObsStRKR1 p4
Was taught how to change from radians to degrees again	Obs2 p2
Asked teacher about standard form – not able to help. Did not use manual.	Int3 p3

2e) Types of difficulties faced when using GC	
Unable to find exponent key so resorted to using scientific calculator	Int1 p1
Needs help with WINDOW function Needs help with TRACE function Has problem finding fraction key	Obs1 p2 p3 p4
Problems recovering from syntax error – ignores error and views graph Searching for fraction key	ObsKR1 p1,6 p4
Trying to change between radians and degrees Returning to HOME screen from graph window Lack of understanding how to move round Y = editor	KeyR1 p2 p6
Problems navigating round GC and finding changing radians to degrees	Jrnl2
Problems navigating round GC and finding changing radians to degrees	ObsStR1 p1
Problems navigating round screen. GC as WP	KeyR2 p3
Had problems working with numerical integration on GC Problems changing radians to degrees Problems deleting efficiently.	Int2 p1 p2 p3
Trying to return to HOME screen – unsuccessful	KeyR3 p1
Problems using INS/DEL and overwriting Trying to move around screen altering previous entry. GC as WP Trying to move around STATS editor and return to HOME screen	KeyR4 p3-5 p6 p7

Too long to find factorial key. Too many brackets needed for standard form. Not entering standard form correctly	Jrnl4
Brackets on everything with standard form. Confusing and tedious	Jrnl5
Searching for numerical integration feature of GC	ObsKR3 p1
GC makes things overcomplicated. Too complicated to work out how to use numerical integration	Jrnl6
Problems changing radians to degrees	Int3 p3
25(1 – (5^400)) = ERR: OVERFLOW quit error times 3. Lack of understanding about the error message √-ve number = ERR: NONREAL ANS quit error, again, clear error. Does not understand error message	KeyR6 p3 p24

2f) Success in using a GC for problem-solving	
Finding solutions to quadratic equations. Number and position of solutions	Jrnl1
Rewrote complete equation again but could have used INSERT	ObsKR1 p4
Using intuition based on numerical solution tan43 = -1.498387339 knew tan45 = 1 so answer was not right	Int2 p3
Having problems with standard form	Jrnl4
Not using standard form feature successfully	Jrnl5
Trying to use GC for numerical integration but not able to find it	ObsKR3 p1
Little clearing of screen between calculations. Basic calculations but efficient	KeyR5
Using GC for numerical integration successfully. Received some training	ObsKr4 p1
Learns to STORE values to variables names and use the variable in equation GOTO error and fix syntax Shortcut to find nCr by using ENTRY Multiple values stored in variables and used in following expression	KeyR6 p8 p18 p19 p29

2g) Changes in a student's level of confidence when using a GC	
Seems very positive about GC. Feels the need to continue to carry scientific calculator as back-up	Int1 p1
Machine switched off due to lack of understanding how to change from screen to screen?	KeyR1 p2
Finding GC useful since he got used to it	Jrnl2
Turns GC off due to frustration at not being able to return to HOME screen Less screen clearing	KeyR3 p2 p7
Very positive about using GC but with some reservations about its features	Jrnl4
Little clearing of screen between calculations. Basic calculations but efficient	KeyR5
Little clearing screen. Seems to be confident using GC.	ObsSRKR3 p3
Used to GC now. Finds scientific calculator small and "*pathetic*"	Int3 p1
Use GC quickly and efficiently	Int3 p2
Using Ans▶Frac or Dec confidently GOTO error and correct syntax. Shortcut to find nCr by using ENTRY	KeyR6 p1 p18 p19

7.1.4 Sam – (School A)

Sam was an eager volunteer to my project. His attendance during the year was very good although he was easily distracted by Ann, whom he sat next to. He found the majority of the work hard and relied heavily on the teacher for step by step guidance when solving problems.

Measures from Research Area 1	**Data Sources**
1a) Extent of use of a scientific calculator	
Using scientific calculator when forgotten GC	Int1 p1

Will use both calculators	p3
Scientific calculator and GC on desk during class. Puts scientific calculator partly back into bag	Obs1 p1
Not used scientific calculator much over the year	Int3 p2

1b) Student's responses to teacher's prompts to use GC	
Teacher prompting to use TRACE function and to reduce $y=x^4$ to $y=(x^2)^2$	ObsKR1 p1

1c) Evidence of unexpected use	
Typing messages Exploring other menus Exploring MATH menus	KeyR1 p2 p3 p16
Exploring MATH menu	ObsStRKR1 p2
Messages to classmate	KeyR2 p4
Exploring MATH menu and STAT menu	KeyR3 p1
Exploring all options on Statistics Menu	KeyR4 p10
Trying to find numerical integration in class	ObsKR4 p2
Taught self to use CATALOG and search for new topics	Int3 p3

1d) Use of GC out of class	
Drawing graphs	Int1 p1
Homework Teaching self to change radians to degrees	KeyR1 p1 p3

1e) Extent of use of GC	
Forgot to take GC into class during first week but had scientific calculator Will use GC for every lesson and homework	Int1p1 p2
Use GC in all mathematics lessons and for doing homework	Jrnl1
Resizing WINDOW to view features of graph and using TRACE	KeyR1 p11
Used GC in every mathematics lesson and for homework	Int3 p2

1f) Different subject areas where the GC is used	
Cosine rule	KeyR1 p1
Probability	ObsStRKR2 p1
Combinations permutations, binomial sequences, graphs, integration	Jrnl2
[e^x], [log], [ln], [nCr], graphs	Int3 p3

1g) Frequency of use of GC with respect to other instruments	
First question: "*Can I take two GCs into examination*?" Going to use both calculators. Took ages to get used to scientific calculator so will keep using scientific calculator until used to GC.	Int1 p2 p3
Used spreadsheet once in mathematics for integration	Int3 p3

1h) Evidence of a student's succinct use of a GC with few errors	
Y=^{2} ERR:SYNTAX clear error Navigating screen – problems with overlapping previous entry. Deletes whole expression rather than alter	ObsKR1 p1 p2
Unsure how to return to HOME screen and turns GC off. Trying to input sin(25) as on old scientific calculator 25sin $\sin^{-1}(20.353)$ = ERR:DOMAIN clear error and then repeated – does not understand error $\cos^{-1}$(ANS (467.7685185)) = ERR:DOMAIN clear error again -2 × – 1 ÷ 17 = ERR: SYNTAX clear error. Similar error again and again – does not understand error.	KeyR1 p1 p4 p6 p13/14/17
53.4. + 12 = ERR: SYNTAX clear error repeated 3 times. Not understanding error message	KeyR4 p4

1-var statistics 23 = ERR:ARGUMENT clear error Sx3=ERR: UNDEFINED clear error, repeated 3 times. Lack of understanding of error message and inexperience of GC function	p8 p11
5.76 + 5.76 ++ 5.76 + 0.16 ... = ERR:SYNTAX clear error	KeyR5 p11
2 × = ERR:SYNTAX 3 times clear error 4nCr-5 ERR:DOMAIN clear error twice -3√(-6= ERR:NONREAL ANS clear error -3-√(6=ERR:SYNTAX clear error lack of understanding about –ve & minus ln(ln(=ERR:SYNTAX clear error ANS ÷ .=ERR :SYNTAX clear error	KeyR6 p6 p10 p24 p26

1i) Apposite use of the GC	
Enter graph equation and draw, but not resizing or TRACE as prompted by teacher	ObsKR1 p5
Rewriting expression in full rather than using ENTRY and altering × to ÷ Resizing graph WINDOW Resizing WINDOW TO find features of graph and using TRACE Repeated ANS × 2 nine times could have pressed ENTER 9 times instead	KeyR1 p8 p9 p11 p17
Typing in long decimal numbers Could have stored value in memory	KeyR6 p6

Measures from Research Area 2	**Data Sources**
2a) Comments from students on the advantages or perceived potential of using a GC	
Confusing but '*fun*' Used as a checker. Need GC or all the "*easy stuff*""	Int1 p1 p2
GC helpful "*if I do not understand teacher, the calculator gives me a diagram... helpful to understand the work*"	Jrnl1
Drawing graphs is good and changing WINDOW	StR1 p1, 2
Through experience he became more aware of how GC functioned	Jrnl2
Likes ANS and ENTRY – speeds up working; demonstrates what teacher trying to say; iterative process. Difficult at first but once familiar with it found it quick and efficient	Jrnl3
Quick to use ENTRY. Can see everything on the screen rather than writing down answers all the time	StR3 p1
Like ANS and ENTRY keys, makes it easier to enter	Int3 p2

2b) Comments from the student on disadvantages or perceived constraints when using a GC	
GC has lots of buttons and looks confusing Press the wrong key by mistake could ruin whole thing	Int1 p1 P2
Bit confusing at first but soon found it easy	Jrnl1
Difficult to understand how to use the functions properly. Annoying process to get nCr or nPr or !	Jrnl2
Difficult to get started on new topic because do not know how to do it on GC; too big; difficult to use at first	Jrnl3
Need to look up how to get started in new topics	StR3 p1
GC too big and teachers do not know where all functions are	Int3 p3

2c) Comments from students about the level of support or training needed	
Did not know how to use numerical integration on GC and teacher unable to help	Obs3

2d)Comments from students about the level of support or training received	
Teacher gives prompt to use GC for resizing graph WINDOW and TRACE to find solutions	Obs1 p1
Required help to find exponent during class session	ObsKR1 p2
Classmate taught him how to change from radians to degrees	StR1 p1
Used manual to find [!] . Carried manual to lesson	StR3 p1
Teachers do not know how to use GC	Int3 p3

2e) Types of difficulties faced when using GC	
Could not find [^] on GC	Obs1 p2
Could not find [^] on GC Problems recovering from syntax error in Y = editor Navigating screen – problems with overlapping previous entry. Deletes whole expression rather than delete	ObsKR1 p1 p2
Trying to edit screen unsuccessfully. Unsure how to return to HOME screen. Turned GC off. Trying to input sin(25) as on old scientific calculator 25sin. Overwrites entry rather than INS. Trying to alter entry unsuccessfully Difficulty navigating round screen Difficulty leaving MODE screen Difficulty deleting on screen Difficulty moving round screen Trying to clear window range and domain unsuccessfully. Turned GC off?	KeyR1 p1 p1,2 p2 p3 p5 p8 p10
Trying to move around screen and alter previous calculation	ObsStRKR1 p5
Trying to delete items in STATS editor. Difficulty exiting STATS editor	KeyR4 p9
Difficulty moving round HOME screen	ObsStRKR3 p3

2f) Success in using a GC for problem-solving	
Checking numerator and denominator separately	KeyR1 p6
Taking answer value as final. No reflection on answer until prompted.	Int2 p1
Combining calculations successfully	KeyR6 p22

2g) Changes in a student's level of confidence when using a GC	
Like a "*normal*" calculator. Not going to bring the scientific calculator in anymore	Int1 p1
Breaking down previous calculation to check answer Checking GC still in degrees. Trying to clear WINDOW range and domain unsuccessfully. Turned GC off? Clearing screen after every calculation	KeyR1 p3 p4 p10
Scientific calculator on desk and using GC.	ObsSR1 p1
Gets confused when screen too messy – likes to clear screen after every calculation	StR1 p3
Clearing screen frequently. Frustration after repeated errors – CLEAR screen 5 times	KeyR4 p3 p4
Very few CLEAR screens.	KeyR5 p9
Reduction in CLEAR screen. Can refer back to answers rather than noting down all the time	StR3 p1
Reduction in CLEAR screen Combining calculations 0.895 sin()Cos() = …	KeyR6 p10-14 p22

7.1.5 Sarah – (School B)

Sarah was eager to volunteer for my project. Her attendance through the year was excellent and she worked very hard during the lessons. In class she sat at a table with four other girls, one of whom sat next to her. Sarah was not easily distracted from her work but was often asked by her classmates for help or advice when working through mathematical problems.

Measures from Research Area 1	Data Sources
1a) Extent of use of a scientific calculator	
Wants to replace scientific calculator with GC	Int1 p1
Replaced scientific calculator with GC	Jrnl2
Put scientific calculator away	Int2 p1
Uses scientific calculator for revision for Pure and for examination	Jrnl11
Only using scientific calculator for examinations "besides that have not used it at all"	Int3 p1

1b) Student's responses to teacher's prompts to use GC	
Working on GC as instructed by teacher Working on GC before instructions being given	Obs1 p2 p2
Working in STATS editor as instructed by teacher. Confidently answers qns	ObsStRcl1 p2

1c) Evidence of unexpected use	
Exploring the GC with manual. Exploring graphs. Writing messages to friends. Exploring GC looking for keys/features/functions	Int1 p1 p2
Using GC to create and store program	KeyR1 p5
Writing messages to friends. Drawing polar roses	Jrnl3
Setting up GC for and drawing polar roses	ObsKR2 p1,2
Messages and polar roses	Jrnl4
Exploring menus – MATH and TEST Drawing polar roses Chatting with neighbour	KeyR2 p3 p5 p13 on
Type things on it and communicating with friends during class	Int2 p1
Messages to friends	Jrnl8
Messages to friends	Jrnl9
Messages to friends	KeyR4 p12

1d) Use of GC out of class	
Learnt a lot through following manual out of class	Int1 p1
Using GC for physics and at home	Jrnl2
Using GC for standard form Using GC to create and store program 2 variable statistics for homework	KeyR1 p2 p5 p11
Taking GC on holiday	Jrnl3
Physics and biology	Jrnl4
Using it for homework	Int2 p1
Homework	KeyR3 p7
Homework	KeyR4 p1

1e) Extent of use of GC	
Using it for homework	Jrnl2
Storing values in GC Using GC to create and store program	KeyR1 p4 p5
Using GC to draw polar roses, converting fractions	Jrnl4
Drawing polar roses, storing graphs and recalling graphs	KeyR2 p3-6
Using it to write programs. Using ENTRY and ANS to make things easier and make it quicker	Int2 p1
Non-mathematics and non-homework Trigonometry graphs	KeyR3 p11 p15

Working with GC during holidays	Jml9
Homework ZOOM in on graph	KeyR4 p1 p14 – 16
Using for differentiation	ObsStRKR2 p2
Graphs and TABLE	ObsStR2 p1
Using it to check differentiation answers	Jml10
Examining TABLE of values from graph	KeyR5 p5
Using GC as "*normal*" calculator for sums can not do in head Statistics revision – tables and calculations	Jml11
ENTRY to alter previous calculations and change your answers, modulus functions, table functions to solve equations Used manual as a start guide initially	Int3 p2 p4

1f) Different subject areas where the GC is used	
Angles for refraction in physics. Curvy graphs. Quadratic equations Mathematics, further mathematics, physics	Int1 p1 p2
PMCC, physics coursework, standard form	Jml1
2 Variable statistics	ObsKR1 p5
Mathematics, physics, atoms, angles, correlation and gradient and polar roses	Jml2
Physics – standard form Statistics – 2 variable statistics	KeyR1 p1 p9
Polar roses	Jml3
Setting GC for and drawing polar roses	ObsKR2 p1,2
Physics and biology, probability, fractions	Jml4
Polar roses, probability	KeyR2 p5
Use in examinations and in biology for magnification values	Jml7
Trigonometry Trigonometry graphs	KeyR3 p1 p15
Messages to friends	Jml8
Biology, physics	Jml9
Differentiation – maxima & minima	ObsStRKR2 p2
Graphs and TABLE feature	ObsStR2 p1
Plotting graphs, calculations involving powers	Jml10
Biology, physics and ICT, mathematics – statistics, modulus	Int3 p2

1g) Frequency of use of GC with respect to other instruments	
Going to use GC permanently rather than scientific calculator	Int1 p2
Using GC in place of scientific calculator	Jml1
Replaced scientific calculator with GC	Jml2
Using GC less because work less complicated and can do a lot in head	Jml3
Uses GC every mathematics lesson and for homework	Int2 p1
Using GC for everything except examinations	Int3 p1

1h) Evidence of a student's succinct use of a GC with few errors	
Problems with standard form. Syntax incorrect. Expecting to be same as handwritten syntax	Jml1
Problems moving around screen. Used to WP and scientific calculator Trying to move around screen and edit expression ÷ = ERR:SYNTAX goto error but then GC off Problems navigating between screens. ANS^^ ==ERR:SYNTAX quit error ERR:ARGUMENT quit error × 2 then again but goto error × 2	ObsKR1 p1 p6 p7 p10 p11
Incorrect use of GC for standard form Difficulties saving quadratic formula as program ERR:SYNTAX twice, then QUIT error	KeyR1 p1 p5
ANS ÷ = ERR: SYNTAX goto error then clears error before any	OSRKR1 p1

amendments Problems navigating round screen. GC as WP? $L_1 0.5^2$ ERR:INVALID DIM clear error but then tries to alter it	p6, 7 p9
9 ÷ 20 - = ERR: SYNTAX goto and amend calculation	ObsKR2 p4
Standard form with many brackets – incorrect syntax for GC ANS ▶ A = ERR: ARCHIVED repeats error 5 times in different forms. Lack of understanding about meaning of error message × = ERR:SYNTAX quit error	KeyR2 p7 p8, p9 p28
ANS + = ERR :SYNTAX clear error ANS × 1 ÷ = ERR :SYNTAX 12 × 12 + = ERR:SYNTAX goto and amend error × 2 = ERR:SYNTAX goto and clear error ANS – 11 + = ERR:SYNTAX clear error ANS ÷ = ERR:SYNTAX clear error ANS → 0 = ERR:SYNTAX clear error	KeyR3 p5 p6 p9 p19 p22 p23 p27
Trying to return to HOME screen from equation editor –navigational Trying to alter previous entry ^10 = ERR:SYNTAX quit error ANS ^ + ERR :SYNTAX quit error 3 times ANS → →. = ERR:SYNTAX clear (book on GC) ANS × = ERR:SYNTAX quit error $Y_1 = 2x^3 - 3x^2 - 3x$ ++2 ERR:SYNTAX goto error and correct it √(16 ÷ 9)) = ERR:SYNTAX goto error and amend it successfully √(-27) = ERR:NONREAL ANS goto and clear screen	KeyR4 p1, 5 p3 p5 p11 p14 p22
ANS ÷ = ERR :SYNTAX clear error	KeyR5 p15

1i) Apposite use of the GC	
Trying to combine ANS and ENTRY	ObsKR1 p1
Using GC for polar roses and to save and recall graphs	Jrnl2
Using ENTRY repeatedly to save time with entering similar calculations Storing values in GC and using values to calculate quadratic formula	KeyR1 p1-3 p4
Using ENTRY to alter previous calculation	ObsStRKR1 p3
Drawing polar roses	ObsKR2 p2
Drawing polar roses and using ANS and ENTRY keys	Jrnl4
Can use arrows to go back and amend entry. Written programs to make things easier. Using ENTRY and ANS – makes things easier and quicker	Int2 p1
Iterative calculation ANS ÷ 5 = …× 16 Trig graphs	KeyR3 p11 p15
Iterative process ANS + (ANS + 8) = eight times	KeyR4 p2
Using it to check answers – graphs and differentiation	Jrnl10
Examining tables of values from graph	KeyR5 p5

Measures from Research Area 2	**Data Sources**
2a) Comments from students on the advantages or perceived potential of using a GC	
"*Graphs are cool*". Likes to play about with GC. Likes to type messages to friends. Wants to replace scientific calculator with GC. Likes being able to recall last sum	Int1 p1 p2
Will find GC more useful as year goes on	Jrnl1
Using GC less because work less complicated can do a lot in head Think polar roses are really "*cool*"	Jrnl3
Quicker to do calculations with ANS and ENTRY keys. Find it easier now know how to use fraction key	Jrnl4
GC very useful in all examinations including Biology	Jrnl7
Found GC very good; good as plaything. Big display makes it easier– can see what is being typed in. Can use the arrows to go back and change things.	Int2 p1

Write programs to make it easier. Use ENTRY to make amendments and use previous answer. Makes it a bit quicker Likes being able to see what is being typed in and using previous calculation and previous answer	 p2
Can just type calculations in as on paper. Also good for plotting graphs to check calculations	Jml8
Using GC to check answers	Jml9
Useful for plotting graphs to help check differentiation answers	Jml10
Likes useful features of statistics tables and calculations	Jml11
GC helped to show graphs and TABLE function to help solve equations GC good because it's got more functions; easier to correct things and redo calculations; being able to use last answer	Int3 p2

2b) Comments from the student on disadvantages or perceived constraints when using a GC	
Have to switch between radians and degrees Pressing wrong button can be disastrous More complicated than scientific calculator when inserting or deleting characters	Int1 p1 p2 p3
Standard form very difficult	Jml1
Keys being pressed when GC put in bag – should use cover	Jml6
Got used to GC. Scientific calculator not as good but have to use it for examination	Jml11
Felt odd going back to scientific calculator for examinations – could not remember where everything was. Kept thinking it was a GC	Int3 p1

2c) Comments from students about the level of support or training needed	
Does not know where exponent key is	Int2 p2
Not allowed to use GC in Pure examination	Jml11

2d) Comments from students about the level of support or training received	
Used instruction manual to go through basics. Self-taught to change from radians to degrees. Treated it like another keyboard or WP? Worked through examples about quadratic equations from manual.	Int1 p1
Taught self to draw polar roses and to save graphs	Jml2
Taught self to STORE values in GC	KeyR1 p4
Taught self to write programs using manual	Int2 p1
Found out how to use TABLE for graphs	ObsStR2 p1
Classmate had to show her where modulus key was. Teachers giving little training. Only one key at a time. Has not used manual very much	Int3 p2 p3

2e) Types of difficulties faced when using GC	
Using manual to get started seemed complicated. Did not know what calculation the manual is doing. Not knowing what was happening if wrong button pressed. Getting used to where everything is on new GC. Very familiar with old scientific calculator. Finding right key can be hard	Int1 p1 p2
Problems moving around screen – used to WP/scientific calculator. Problems combining ANS and ENTRY Inexperienced using INS on GC Trying to move around screen to edit Error and then trying to recover but lack of understanding of what to do next Problems moving between screens. Problems moving around screen	ObsKR1 p1 p2 p3 p6 p7 p10

Problems with standard form results in putting everything in brackets	KeyR1 p1
Problems navigating round screen. GC as WP? Navigating issues after error message	ObsStRKR1 p6 p7, 9
Trying to navigate round HOME screen Trying to return to HOME screen. Calculating standard form using incorrect syntax Some difficulty navigating around HOME screen Lack of understanding of error message	KeyR2 p3 p7 p9 p17 p9
Keys being pressed on GC when in bag	Jrnl6
Cannot find powers key	Int2 p2
Trying to return to HOME screen from Y= editor Trying to alter previous entry	KeyR4 p1 p3
Slip back to scientific calculator ways – entering trigonometric calculation the wrong way round	ObsStRKR5 p3
Could not find fraction key – unexpected to be in menu not on a key Navigating round GC when looking for new feature can be tricky	Int3 p3

2f) Success in using a GC for problem-solving	
Syntax problems with standard form. Expecting to be same as handwritten	Jrnl1
Uses fraction key throughout Standard form– incorrect syntax for GC. Manages with many brackets Using ANS and ENTRY successfully	KeyR2 p7 p12
Using ENTRY / ANS to amend previous calculation & use previous answer.	Int2 p1
Iterative process ANS + (ANS + 8) = eight times	KeyR4 p2
Using it to check answers – graphs and differentiation	Jrnl10
Examining tables of values from graph	KeyR5 p5

2g) Changes in a student's level of confidence when using a GC	
Confident enough to explore using manual. Concerned if pressing wrong button	Int1 p1 p2
Looking forward to learning more about GC. Hope to find it more useful as course progresses	Jrnl1
Aware of shortcuts. Trying to combine ANS and ENTRY Little use of CLEAR screen	ObsKR1 p1 p8
Confident enough to follow manual to draw graphs not on syllabus. Saving and recalling graphs and teaching others to do the same on their GC	Jrnl2
Using ENTRY repeatedly to save time with entering similar calculations Storing values in GC and using values to calculate quadratic formula Attempting to save quadratic formula as new program – as in manual	KeyR1 p1 p4 p5
Using GC less because work less complicated can do a lot in head	Jrnl3
Using ENTRY to alter previous calculation Little use of clear screen	ObsStRKR1 p3 throughout
Using GC to draw polar roses – not on syllabus	ObsKR2 p2
Likes to calculate things a couple of times to be assured of the right answer	Jrnl5
Uses decimals - fractions throughout Drawing polar roses Understanding how to navigate round HOME screen Limited use of clear screen	KeyR2 p5 p14 throughout
Make things easier by writing programs, and using arrow keys to make amendments. Using ENTRY and ANS to make things quicker and easier	Int2 p1
Multiple screen clear throughout [29 times p5][13 times p11][31, 36 times p12][20 times p16][34 times p25][35 times p26][50 times p27]	KeyR3
Like GC loads better than scientific calculator	Jrnl8
Sums easy enough to do in head. Using GC less and less	Jrnl9
Iterative process ANS + (ANS + 8) = eight times Clearing screen 13 times	KeyR4 p2

Using it to check answers – graphs and differentiation	Jrnl10
Multiple clear screen throughout. Few single clear, many multiple clear	KeyR5 p19, 20, 33
Frequent multiple clear screen	ObsStRKR5 p2,3
Using GC less and less and was doing more calculations in her head.	Int3 p2

7.1.6 Steve - (School B)

The quantity of data collected for Steve are significantly less than the quantity that was collected for the other students within the same school. This is due to the fact he withdrew from the AS Level Mathematics course and all his other AS Level courses at the beginning of January 2004. However I still include his data in my study as comparisons can be made with the other students during the first term of use of the GC.

Measures from Research Area 1	**Data Sources**
1a) Extent of use of a scientific calculator	
GC too "*special...scary*". Will rely on scientific calculator Not used GC previously. Will probably use GC every lesson. Continuing to use scientific calculator on regular basis	Int1 p1 p2
Using scientific calculator less	Jrnl1
Using scientific calculator for fractions. Using scientific calculator more because GC complicated. GC different and difficult to use	Jrnl2
1b) Student's responses to teacher's prompts to use GC	
Teacher says "*you should have your calculator in front of you*". Steve did not have GC on desk until she said this. Teacher explains how to use GC for PMCC. Follows instructions successfully	Obs1 p1 p3

1c) Evidence of unexpected use	
Writing messages to classmate	Int1 p1

1d) Use of GC out of class	
Using in class for more difficult work. Using GC at school only	Int1 p2
Using GC at home – trigonometry	KeyR1 p1
Using GC at home	Jrnl1
Using in other non-mathematics lessons	Jrnl2

1e) Extent of use of GC	
Will use scientific calculator at home but GC at school. No unprompted use?	Int1 p2
Using GC in lessons and at home	Jrnl1
Using GC and providing answers before being instructed	Obs1 p1
Using GC in Physics	Jrnl2

1f) Different subject areas where the GC is used	
Statistics	ObsKR1 p3
Physics	Jrnl2

1g) Frequency of use of GC with respect to other instruments	
Using scientific calculator rather than GC. GC too special Still using scientific calculator at home and GC at school	Int1p1 p2
Using scientific calculator for fractions. GC more complicated so using scientific calculator more	Jrnl2

1h) Evidence of a student's succinct use of a GC with few errors	
ERR: DOMAIN x 2 $\sin^{-1}(>1)$ ERR: INVALID DIM ERR: SYNTAX	KeyR1 p1-2 p3 p5
ERR: DIVIDE BY 0 ERR: SYNTAX GC off?	KeyR2 p2 p3

1i) Apposite use of the GC	
Using long version of Σx and Σx^2	KeyR1 p8

Measures from Research Area 2	**Data Sources**
2a) Comments from students on the advantages or perceived potential of using a GC	
Talking to classmate. Believes he '*needed GC*' for course. Corresponds with teacher's view. Able to store many different values. Thinks GC is initially quite good. Seems like a basic calculator. No real problems. Using GC for harder work.	Int1 p1 p2

2b) Comments from the student on disadvantages or perceived constraints when using a GC	
Graphs from manual too difficult. Manual hard to read. Spent extra time looking for key to press. Lots of different functions – "*quite scary*" Pressing wrong button can be daunting	Int1 p1 p2
Omitted brackets give wrong answer Fractions difficult on GC. Not fraction key. GC more complicated	Jml2

2d) Comments from students about the level of support or training received.	
Trying to use manual but found it too difficult	Int1 p1

2e) Types of difficulties faced when using GC	
Manual difficult to read. Hard to realise which button to press. Pressing wrong button can be daunting	Int1 p1 p2
Frustration when mis-key made. Deleting one character at a time. Could clear and achieve same. No use of INSERT	ObsKR1 p1
Clear screen multiple times	KeyR1 p3
Problems navigating round screen	ObsStKR1 p2,3
Problems navigating round screen	ObsKR2 p2
Problems navigating round screen	KeyR2 p13
Omitted brackets produce errors with answer. Scientific calculator did not do this? Fractions difficult on GC. Not fraction key. GC complicated	Jml2

2g) Changes in a student's level of confidence when using a GC	
New tool is "*scary*". Does not want to risk using new tool. Pressing wrong button can be "*scary*"	Int1 p1
Steve working on problem and providing answers before asked	Obs1 p1
Calculates fraction then checks each part of numerator and denominator	ObsKR1 4-5
Using GC more.	Jml1
Using long version of Σx and Σx^2	KeyR1 p8
Did not use ENTRY or INSERT instead deleted calculation	KeyR2 p2
Confidence in GC diminishing	Jml2

7.2 Emergent Themes

These emergent themes are in addition to the research questions I previously set out. I include them here as they offer an alternative perspective on the students' appropriation of their GCs.

I started by placing all of Sarah's evidence in chronological order and began to read through it all coding each category or theme as it emerged. I re-read Sarah's data, redrafting and refining my categories and then applied them to the other two students from school B. (See 8.3 Emergent Themes) The final list of categories that emerged is as follows:

- Attitude to Technology
- General Use
- Frequency of Use
- Exploring the GC
- Learning & Using Specific Features of the GC
- Navigating Around GC
- Navigating Around the Screen
- AS Level Mathematics Topics
- Mathematics not on AS Level Mathematics Syllabus
- Non Mathematics Work
- Use in Other Subjects
- Errors
- Frustration

Once I developed this list I re-read all the data from each student with these in mind and assigning the categories where necessary.

Due to space restrictions here, I choose to restrict my reporting of the results from all the students in my study to David, Sarah and Steve - the students from school B. I chose these students over and above those from school A as the students from school B have a wider range of use of their GCs over the course of the year.

7.2.1 David

Attitude to Technology

Using it everyday – like scientific calculator. Very easy – did not need to use manual; logical to use; playing around with it. Lots better than scientific calculator. Scientific calculator limited. TI-83+ has more memory and can do lot more with it. Interested in using it Been using GC 2 or 3 times a day – just for minor things. Will be using it more and more as course progresses. Considers it very useful. Has not been carrying scientific calculator around with him anymore	Int1 p1 p2
Feel it is quite easy to use and do not have much trouble with it. No disastrous experiences (was he expecting some?)	Jml1
Finding GC "*quite easy*" although has not used it for anything new. Mentions this several times – is he disappointed?	Jml2
Wrote about how the rest of the GC was ok. Not enthusiastic?!	Jml3
Using GC in all lessons but has to remember to bracket everything. Refers back to the scientific calculator and how it was easier. Did not need to use any of GC specific functions during examination. Been useful for 2 var statistics and getting Sxy etc the rest is what I would use scientific calculator for Perceives it as very useful. Same functions as previous calculators – nothing	Int2 p1 p2

really surprising	
Calculator very useful during revision. Familiar with all the functions therefore is lots easier to use and am quicker. Bracketing everything which is tedious	Jml4

General Use

Good to check answers with – type in equation and it can print answer out for you. Drawback – it's quite big. "*All calculations seem to be ok. When it comes up with point* (.756) *it does not have nought point and that sometimes throws me.*" Has used GC for GCSE Mathematics statistics coursework	Int1 p1 p2
Clears screen between every calculation Doodling on arrow keys	KeyR1 p3 p11
No disastrous experiences because no time to go through all functions – (did he know <u>all</u> the functions on his scientific calculator?) not used it for more challenging stuff yet.	Jml1
Doodling(?) with first few keystrokes of lesson. Doodling again 858585...85 Later mentioned he did not realise GC was tracking ALL his keystrokes. Just thought it was when he pressed Enter!! Repeated calculation after he had cleared screen – could have used ENTRY Repeated calculation (broken down into 2 parts) after he cleared screen. Could have used ENTRY	ObsStR1p1 p2 p3
Error – divide by 10 rather than 100. Rewrote entire calculation rather than use knowledge of place value or use ENTRY and alter entry Repeated calculation Regular clearing of screen after each calculation. Repeated calculation with errors! Then confirms previous answer CLEAR screen 7 times Confirming calculation by breaking it into parts and then rebuilding it Clear screen 9 times Clear screen and then repeated calculation Clearing screen after every calculation Doodling by entering ,,,,,, Repeated calculation	KeyR2 p1 p2 p5 p11 p14 p15 p16 throughout p25 p26
Refers to trouble with brackets and standard form Been useful for 2 var statistics and getting Sxy etc the rest is what I would use scientific calculator for. Fraction key not like the scientific calculator	Int2 p1 p2
Clearing screen after every calculation. Repeated calculation	KeyR3 p1/2
Clearing screen after every calculation Great deal of multiplying by 10 or 100 Missed opportunity to use ENTRY and make minor alterations to calculations. Repeated calculation with standard form in calculation Broke down calculation to check answer	KeyR4 p1-3 p1/2/6 p3/4/5 p11

Frequency of Use

Been using it regularly within mathematics. Using it on a daily basis in and out of school	Jml1
Using it every lesson and at home lots. Not using scientific calculator at all – only if it's by my computer at home and need it for basic calculation	Int2 p1

Exploring the GC

Playing around with it – did not even have to read the manual	Int1 p1
Exploring LIST menu and MATH menu within. Exploring DRAW menu Drawing 'union jack'. Exploring iterative process ANS × 5 = (15 times) Exploring TRACE and moving between GRAPH and HOME screens	KeyR1 p9 p10 p11

Exploring how GC works with negative numbers and if he needs brackets Exploring or doodling on Function keys	KeyR2 p6 p24
Broke calculation down first and then built it up. Lack of trust of GC?	KeyR3 p11

Learning & Using Specific Features of the GC

Learning how to delete items from Stat Data Editor. Did not use ENTRY to enter very similar calculation Confusion with radians or degrees. Same calculation 4 times – could have used ENTRY or ANS Change radians to degrees. Re-enters previous calculation Learning to delete equations from graph editor	KeyR1 p4 p8 p9 p10
Learnt how to enter and use 2 variable statistics	Jml1
Did not store values to Variables names or used ENTRY Not taking advantage of shortcuts : 0.56 instead of ANS Calculation with brackets but without × then confirms answer by including × Not taking advantage of ANS in continuing calculation Did not take advantage of ENTRY to make one alteration to lengthy calculation Using ENTRY albeit for a repeated calculation	KeyR2 p2 p8 p11/12 p16 p20 p27
Problems with standard form. Says it's different from his scientific calculator and needs to put brackets round every calculation. Check Steve and Sarah also	Jml3
Does not take advantage of ENTRY	Int2 p2
Using STORE feature of GC to keep accuracy of answers	Jml4
Missed opportunity to use ENTRY and simplify calculation Missing brackets again with denominator 2 ÷ (2×2) -1 = -0.5 but really wanted 2 ÷ 3? Missed opportunity to use ENTRY and INSERT to alter previous entry Missed many opportunities to use ENTRY and make minor adjustments to calculations	KeyR3 p5 p7 p8 p 12/13/14

Navigating Around the GC

TEST menu (logic tests) but meant to find STAT TESTS (within STATS menu) Return to HOME screen and then CLEAR 5 times	KeyR1 p8
Power key - not what was expected	Int2 p2

Navigating Around the Screen

Learning how to delete items from Stat Data Editor Efficient use of how to delete statistics data items Trying to find previous entry to alter it?	KeyR1 p4 p6 p10
Trying to alter previous calculation by UP and LEFT. Trying to transfer knowledge of PC? Trying to move round screen like WP again?	ObsStRcl1 p2 p3
Trying to move around screen like WP	KeyR2 p7, 25

AS Level Mathematics topics

Not sure what specific topics but if we do a course on line graphs, solving equations on line graphs	Int1 p1
STATS Menu and 2 variable statistics Trigonometry	KeyR1 p1 p8
Graphs & Pearson's two variable statistics	Jml1
Product moment correlation coefficient	Jml2
Normal Distribution (wrote it on display!) Standard form	KeyR2 p4 p10/11
Statistics, trigonometry	Int2 p1

Been useful for 2 var statistics and getting Sxy etc the rest is what I would use scientific calculator for	p2
Product Moment Correlation Coefficient , x bar and y bar, linear regression	Jrnl4
Trigonometry	KeyR3 p3/4

Mathematics not on AS Level Mathematics Syllabus

None	

Non Mathematics work

Doodling	KeyR2 ...

Use in Other Subjects

Physics because it uses lots of mathematics functions. For basic calculations in any lesson but not used graphs etc. No call for it in other lessons really	Int1 p1
Physics course-work. Refractive Indexes – physics	Jrnl1
Using it in other subject for simple calculations	Jrnl2
Photoelectric effect – physics & chemistry. Problems with standard form	Jrnl3
Physics, chemistry	Int2 p1

Errors

ERR: DATA TYPE recovering form error. Lack of understanding how to do this efficiently ERR:SYNTAX clears error	KeyR1 p9 p12
ERR:SYNTAX clears error ERR: SYNTAX (- –) clears error. Gets back on track with – - quite quickly ERR: DIVIDE BY 0 GC off? ERR: SYNTAX 4 times in succession. clears error ERR:SYNTAX (missing bracket) clears error	KeyR2 p5/6 p7 p8 p9 p13
ERR:SYTNAX (extra operand) clear 3 times = clear error & clear screen ×2 ERR: SYNTAX clear error and clear screen. ERR:SYNTAX inclusion of commas - clear 3 times	KeyR4 p8 p9

Frustration

TEST menu (logic tests) but meant to find STAT TESTS (within STATS menu) Return to HOME screen and then CLEAR × 5 – minor frustration Clear screen 8 times – frustration or lack of understanding?	KeyR1 p8 p10
Error and then machine off? Seems no other explanation. Frustrated with error?	KeyR2 p8
Clear screen 31 times!! Frustration with wrong answer? Mis-type	KeyR3 p11

7.2.2 Sarah

Attitude to Technology

Like keyboards & stuff. Going to replace scientific calculator with GC Useful for lots of subjects. Can not just press delete like scientific calculator. Recall last calculation 'which is fun' 'Technology one of my favourite things', computer, trains	Int1 p1 p2 p3
Found it very useful…use of GC has been lot of fun & very easy to learn… looking forward to learning more… find it more useful as year goes on and certainly in examination period	Jrnl1
Using GC in place of scientific calculator. Polar roses on different GCs	Jrnl2
Enjoying typing messages to friend. Still playing with polar roses – think it's cool. Taking GC on holiday	Jrnl3

Drawing polar star in class instead of listening?	ObsKR2 p1/2
Lot quicker to do calculations. Recall last calc; alter them; use formulas using ANS key. Will find probability easier now know how to display fractions. Still enjoying making polar roses & other types of polar graphs	Jrnl4
Very useful in examinations	Jrnl7
Using GC for conversations but novelty is wearing off but still like it loads better than scientific calculator	Jrnl8
Using the very useful feature of STATS tables and calculations to check answers. Wish I could take it into my Pure examination but have to use scientific calculator which is not as good as GC	Jrnl11
Easier to correct things. Can not be without GC in AS Mathematics Showing off to friends	Int3 p3 p4

General Use

Double checking calculation	OSRKR1 p8
Repeat calculations to confirm answer	Jrnl5
Pressing the wrong buttons because of a cold(?!) Not using cover on GC and keys being pressed when its in her bag	Jrnl6
Multiple screen clearing	KeyR3 p1 on
Checking answers with GC	Jrnl9
Solving quadratics - long way not using GC to full. Did use GC to solve quadratics in beginning. Forgotten that it could do this?	ObsStRcl2 p2-5
Using GC as checker	St Rcl2 p.1
General sums & sums involving powers	Jrnl10
Small slip – possibly indicating use of scientific calculator recently. $0.5\tan^{-1}$ rather than $\tan^{-1}(0.5)$	ObsStRcl3 p3
Using as normal calculator for sums can not do in her head	Jrnl11

Frequency of Use

Using GC less – more work in head. Less in physics as well as mathematics	Jrnl3
Not using GC as much because calculations are easier to do in head	Jrnl9
Using GC for conversations but novelty is wearing off but still like it loads better than SC	Jrnl8
Not conversing as much with friend	Jrnl10
As year went on doing more mental mathematics	Int3 p2

Exploring the GC

Using instruction manual. Graphs & Radians to degrees in science Play when teacher 'babbling'. Reading manual – seeing potential of GC	Int1 p1
Using instruction manual to do polar roses	Jrnl2
Storing numbers in variables and using these with quadratic formula not the example from the manual Trying to save program – quadratic formula – unsuccessfully (not in manual)	KeyR1 p4 p5
Now know how to use fractions	Jrnl4
Exploring menus on GC Drawing polar rose and polar stars. Storing graphs	KeyR2 p.3 p4-6
Solving quadratics - long way not using GC to full. Did use GC to solve quadratics in beginning. Forgotten that it could do this?	ObsStRcl2 p2-5
Teachers only focus on one button at a time Not really looked at manual (contradiction) Brief look at manual. Will look at manual more in A2. Polar roses	Int3 p3 Int3 p4

Learning & Using Specific Features of the GC

Getting used to GC after using scientific calculator for so long	Int1 p2

Problem with standard form and need to use brackets	Jrnl1
Polar roses, saving graphs, degrees to radians	Jrnl2
Learning to combine ANS and ENTRY. Trying to return to HOME screen Frequent and early use of entry (altering or using previous entry) Storing numbers in variables and using these with quadratic formula not the example from the manual Trying to save program – quadratic formula – unsuccessfully (not in manual)	ObsKR1 p2,p10 p1,2 p4 p5
Using ANS at beginning and in middle of calculation. Entry. ERR:INVALID DIM and trying to correct it	ObsStRKR1 p3, 4 p9
Probability – calculating with fractions – unable to do it. Classmate asked teacher and then me. Sarah did neither. Explained to her at end of class	ObsKR2 p4
Alter last calculation; using ANS key. Now know how to display fractions	Jrnl4
Using fractions key to convert decimal answer to fraction Drawing polar rose and polar stars. Storing & recalling graphs	KeyR2 p1, 2 p4, 5
Can type in formulas as on paper instead of having to use brackets & different calculations. Good for plotting graphs to check where x needs to be found	Jrnl8
Cube root key – class mate did not know where key was. Sarah had no problem – used it before? Solving quadratics - long way not using GC to full. Did use GC to solve quadratics in beginning. Forgotten that it could do this?	ObsStRcl2 p2-5
Statistics tables and calculations for LineReg & Correlation Coefficient	Jrnl11
Forgotten where everything was on scientific calculator STATS menu, ENTRY button, Modulus – problem locating it Fraction key hard to find. Using GC not really a problem	Int3 p.1/2 p2 p3

Navigating Around the GC

Pressing wrong button – takes time to find right one. Trying to transfer knowledge of scientific calculator to GC and experiencing problems	Int1 p2
Struggling to exit statistics menu Trying to return to HOME screen	ObsKR1 p1 p10
Forgotten where everything was on SC Had problem locating modulus function Fraction key hard to find. Not really a problem	Int3 p1/2 p2 p3

Navigating Around the Screen

Trying to alter current entry like WP Trying to edit previous entry & trying to move around screen	ObsKR1 p1 p6,10,11
Trying to move round screen like WP (?)	ObKRSR1 p6, 7, 9
Trying to move round screen	KeyR2 p4

AS Level Mathematics topics

Storing values in variables and using these with quadratic formula but not the example from the manual Entering statistics data in STATS editor. Calculating 2 var statistics	KeyR1 p4 p9 p10
Probability – calculating with fractions – unable to do it. Classmate asked teacher and then me. Sarah did neither but I explained it to her at end of class	ObsKR2 p4
Probability	Jrnl4
Calculating with fractions – no problems	KeyR2 …
Changing from degrees to radians	KeyR3 p1
Formulas, graphs	Jrnl8
Solving differentiation problems – quadratics –	ObsStRcl2 p2-

	5
Using it for sums involving powers. Plotting lots of graphs and using them to check answers for differentiation	Jrnl10
Statistics tables and calculations for LineReg & Correlation Coefficient	Jrnl11

Mathematics not on AS Level Mathematics Syllabus

Creating Polar star	ObsKR1 p1
Polar roses, saving graphs	Jrnl2
Unsuccessfully trying to create and save a program for quadratic formula (not in manual)	KeyR1 p5
Polar roses	Jrnl3
Polar roses & other polar graphs	Jrnl4
Drawing polar rose and polar stars Storing & recalling graphs	KeyR2 p4-5 p6,7
Polar roses, chatting	Int3 p.4

Non Mathematics work

Writing messages	Int1 p1
Typing messages	Jrnl3
Conversations	Jrnl4
Conversations	KeyR2 p13-17
Conversations	Jrnl8
Conversations in IT	Jrnl9
Chatting in IT	Int3 p2

Use in Other Subjects

Science – radians to degrees	Int1 p1
Physics coursework	Jrnl1
General calculations in physics & Biology. Physics test	Jrnl4
Examinations – biology examination – calculating magnification values	Jrnl7
Using it in physics & biology. conversations	Jrnl8
Physics & Biology coursework	Jrnl9
Conversations in IT	Jrnl9
Physics & Biology	Jrnl11
Biology minimum, IT just for chatting, Physics – lots Chatting in IT	Int3 p.2

Errors

ERR: ARGUMENT. ERR:SYNTAX	ObsKR1p11
Unsuccessfully trying to save program for quadratic formula (not in manual)	KeyR1 p5
Trying to alter error from $L_1 0.5^2$ = ERR:INVALID DIM	ObsStRKR1 p9
Trying to create polar star graph – no error but mistakes made	ObKR2 p1/2
ERR:ARCHIVED several times	KeyR2 p8, 9
ERR:SYNTAX Goto error and amend entry Clear error rather than amending entry	KeyR3 p9,19 p23, 27

Frustration

Multiple screen clear throughout [29 times p5][13 times p11][31, 36 times p12][20 times p16][34 times p25][35 times p26][50 times p27]	KeyR3

7.2.3 Steve

Attitude to Technology

Have not used GC for 'extravagant stuff like drawing graphs'. General attitude to ICT is reserved, cautious, lacking enthusiasm. "*ok*", "*fine*", "*scary at first*". Did not want to risk using GC in other classes. Can store billions of values. Needed to have a GC GC seems quite good (4 out of 5). When you make a mistake it is "*quite scary*". Seems like a basic calculator but "*very advanced*". Will use GC at school (every lesson) but will still have and use scientific calculator at home. More advanced tool for harder mathematics. Scientific calculator not able to handle data or have right functions. Does he feel he's pushed into using GC?	Int1 p1 p2
Using GC at home and at school. Has "*better understanding*" of basic functions	Jml1
Comment on scientific calculator vs. GC re brackets and index. Scientific calculator worked but GC did not – obviously using both calculators still. GC not as easy as first thought. GC is "*different and difficult*" and is using it less and less. Started using scientific calculator more and more	Jml2

General Use

Writing messages – "*chatting*" with classmate during lessons Seems like a basic calculator but "*very advanced*". More advanced tool for harder mathematics	Int1 p1 p2
Checking calculation for S.D. by reworking numerator and denominator	Obs1 p5
Talk of using scientific calculator but chooses to use GC for simple calculations and simple trigonometry	KeyR1 p8
Using GC for very simple calculations – too simple. 1+2 = 3	Obs2 p1

Frequency of Use

Exploring GC– found manual complicated. Too much info Probably use GC every lesson but still have scientific calculator at home	Int1 p1 p2

Exploring the GC

Complicated to draw graphs. Manual is just impossible to read because there is too much there. Finding it difficult to locate necessary keys - π. Talks about storing values in GC when he first looked – billions of variables!!	Int1 p1
Drawing y=10, y=-10 exploring GC or exploring mathematics? Looking for 2 Var Statistics at behest of teacher	Obs1 p1 p4
Testing the GC to see what would happen with ÷M= ??? Exploring graph editor Exploring graphs and gradients?	KeyR2 p7 p9 p11

Learning & Using Specific Features of the GC

Complicated to draw graphs and use manual. Finding basic functions 3 + 3 is ok. Can store billions of values	Int1 p1
Entered part of calculation, changed mind and then deleted calculation rather than CLEAR. Missed opportunity to use shortcut of previous entry and insert	Obs1 p2
Trying to store value in A?	KeyR1 p2
Does not know where fraction key is on GC	Jml2

Navigating Around the GC

Comparison to scientific calculator – finding it difficult to locate key e.g. π. Spent extra time searching. Basic function 3 + 3 "*nothing hard about that*"	Int1 p1

Navigating Around screen

Some lack of understanding about how to move around HOME screen	Obs2 p2
Trying to move around graph editor screen Trying to navigate round HOME screen and alter previous calculation	KeyR2 p9 p12-14

AS Level Mathematics topics

Drawing graphs – complicated at first. Drawing graphs	Int1 p1
STATS data	Obs1 p3
Standard form	Jrnl1
Trigonometry Arcsine	KeyR1 p1
Drawing graphs – linear graphs (exploring gradients?)	KeyR2 p11

Mathematics not in AS Level Mathematics Syllabus

None	

Non Mathematics work

Writing messages to David	Int1 p1

Use in Other Subjects

Did not think he would use the GC outside Mathematics class because it is special equipment	Int1 p1

Errors

When you press the wrong button it is quite scary	Int1 p2
Correcting error $\sin^{-1}(1.5)$ = ERR:DOMAIN Creates error when entering Statistics data. ERR: INVLAID DIM. Just deletes data does not try and alter anything. ERR:SYNTAX from 7 + = switches GC off ERR:SYNTAX (double – –) amends entry using GOTO and corrects error	KeyR1 p1,2 p4 p5 p6
Calculation entered in error. Rewrote rather than correct it by using ENTRY ERR:SYNTAX GC off	KeyR2 p2/3 p3

Frustration

Stuck in WINDOW? Must have turned GC off	Obs1 p1
Creates error when entering Statistics data. ERR: INVLAID DIM. Just deletes data does not try and alter anything. Running away? ERR: SYNTAX from 7 + = switches GC off. Frustration?	KeyR1 p4 p5
ERR: SYNTAX GC off – frustration?	KeyR2 p3

Chapter 8 – Discussion of Results

The main aim of my thesis is to explore students' appropriation of a GC during their AS Level Mathematics course.

This chapter is set out in two main sections. The first section discusses the students' activities with their GC based on the measures derived from my research questions, research areas and hypothesis (sections 3.2 and 3.3 respectively). I consider each research question and then examine what use of the GC was employed by each of the six students' in turn with that research question as the focus. The second section 8.2 Emergent Themes considers the categories that emerged from the data. These themes are in addition to the Research Questions and I include them here as they provide an alternative perspective on the data. I adopted a grounded approach to the data and identified themes that arose after reading and reviewing the data multiple times. I describe the use of GCs by the three students from school B under these emergent themes. The focus is on these three students for two main reasons – the space available within this thesis and also that the students at school B illustrated a wide range of use of the GC during the course.

8.1 Measures Informing the Research Questions

The measures were determined by considering the hypothesis, the research areas and research questions arising from them. The measures are ways of analysing the data collected as well as focussing in on elements of each research question. I will take each measure in turn and discuss each student's use with respect to it, and then summarise before taking the next measure.

8.1.1 Research Area 1: What is appropriation of technology and how does it manifest itself?

8.1.1.1 Extent of use of a scientific calculator - Research Area 1, Measure (a)

Initially Ann spoke of replacing her scientific calculator with her GC but she thought that she would have to get used to it first. This was confirmed when she mentioned in interview that she carried both her scientific calculator and her GC to school and would choose which one to use depending on her needs. After examining the data, it was apparent that she still relied on her scientific calculator quite significantly until at least January. After this time there was very little reference to her scientific calculator but this could be attributed to Ann's absences from class and the data collection sessions, alternatively this may be because she was replacing it with her GC as the course progressed. The quantity of data taken from the Key Recorder indicates that although there were times when she was using her GC for significant periods, there were also occasions when the level of use was considerably lower than her two classmates who were also on the project. This is possibly due to her level of attendance during the latter part of the year.

When David received his GC he said he put away his scientific calculator and the only time he used it was during the examinations where GCs were not permitted. In January David said that he had used his scientific calculator but only when he was sitting at his computer at home, when it was near and he needed to perform a basic calculation. The quantity of key-stroke data generated indicated that David used his GC extensively throughout the rest of the year.

Max took some time to replace his scientific calculator with his GC. In the first interview he stated he would carry his both calculators just in case of problems, and indeed Max did face some problems. When the class began to study trigonometry he found that all his answers were different from those of the other students. His GC was set to the default – radians – and he did not know how to change to it to degrees. His teacher was unable to help and he chose not to ask his fellow classmates who were also involved in my project for any help despite the fact they had already found out how to do this for themselves. To overcome the problem Max resorted to using his scientific calculator whenever he was working on trigonometry. After a couple of weeks Max explained his problem and asked how he could change his GC to degrees and after a brief explanation from me he then was able to use the GC for trigonometry and all his other mathematics work.

Sam's first question after he had volunteered for my study was "*Am I allowed to take two calculators into the exam*?" and even during the first interview he said he was going to use both calculators until he was more familiar with the GC. Sam clearly thought that there may be reasons to need both calculators and that any problems may be avoided by having both calculators available to him. At the end of the course Sam reflected on the amount he had used his scientific calculator during the year and he said that he hardly ever used it. However, there were times during the first few months when he was observed with both his scientific calculator and his GC on his desk during mathematics lessons. The GC was in front of him and the scientific calculator was in his pencil case. This seemed to indicate he felt the need to have the scientific calculator there as a security measure – to ensure he was able to perform calculations even if his GC seemed too complicated.

From the first day Sarah was inclined to put away her scientific calculator and replace it with the GC. She was extremely keen to use the GC and the Key Recorder evidence confirms this. Throughout the year Sarah admitted that she only used her scientific calculator for the revision and examination of the first Pure Mathematics module (where GCs are not permitted).

During the first term Steve was ill at ease using the GC. He perceived the GC as a "*special tool*" to be reserved for class work only and he mentioned at the beginning of the term that he would rely on the scientific calculator for work at home. This level of use of the GC seems to change during the middle of the term as by then he said that he understood it more. However by the end of the first term he again found the GC difficult to use (e.g. fractions, standard form) and stated that he would be returning to use his scientific calculator. Steve mentioned that he would only use his GC in mathematics classes which indicates that he had limited confidence in his own ability to use the GC and that he required assistance from the teacher or his peers when using this new instrument.

All *the students in my study began the year stating that they were considering putting their* scientific calculator to one side and relying on the GC completely. But in fact it was only Sarah who completely adopted the GC instantly, examinations excluded. David and Max were inclined to adopt the GC but due to navigation or syntax problems they relied on their scientific calculators to some extent during the year. Steve and Sam were both reluctant to use their GC and created barriers to using them (see 9.4.3 Barriers to Appropriation). They cited examples of problems they faced (navigation or syntax) or reasons they did not want to carry the GC – it was too big and heavy!

8.1.1.2 Student's responses to teacher's prompts to use GC - Research Area 1, Measure (b)

Initially Ann mentioned that the GC would be useful for checking her answers and this was a reflection of her teacher's view of the GC as well. Within the first few weeks Ann followed her teacher's prompts exactly to resize her graph WINDOW but during the remainder of the year there is no evidence of Ann doing this without prompts from the teacher. She followed prompts if the instructions were given key-stroke by key-stroke but she seemed unable or unwilling to adopt these procedures when she was working on her own.

At the beginning of the data collection period, David appeared to be reluctant to use his GC and was prompted to retrieve it from his school bag by his teacher. However for the rest of the session he was keen to use the GC to calculate statistics and followed the teacher's instructions to use the GC. Apart from when working on the statistics module, David's teacher did not appear to offer many prompts or training to use the GC so it is not possible to comment further on how he responded to prompts to use the GC

When solving quadratic equations, Max followed his teacher's prompts exactly, key-stroke by key-stroke, to draw a graph, resize the graph WINDOW and TRACE the graph. On several occasions during an observed lesson Max repeated the process previously taught to resize the graph WINDOW without further instruction from his teacher. However during the year Max said that although he was altering the WINDOW size as per previous instruction, he found it annoying to be continually changing the size of the graph WINDOW. He was using the GC unprompted by the teacher but this does not indicate if he was selectively using this procedure or if he was changing the WINDOW for every graph, irrespective of whether it was necessary. In the final interview Max referred to using the GC to compare the answers he had calculated, in other words he viewed the GC as a checker which is how his teacher positioned it.

In school A during one observed lesson, the teacher prompted the students to use TRACE feature and to resize the WINDOW and Sam responded by following the example key-stroke by key-stroke. There is no evidence to suggest that Sam used these procedures later in the year or at any other time than under direct instruction from the teacher.

Over the course of the year, the teachers made limited prompts to use the features of the GC. In school B the teacher directed the students to use the GC to enter data and then make statistical calculations on the data. In school A the teacher provided some training to resize the graph WINDOW and led the students through examples to TRACE the graph and find points of significance. A great majority of the work on the GC could have been done on a scientific calculator and teachers took only minor advantage of the special features of the GC. In this particular instance this was not a particularly useful measure. If the teachers had made more extensive use of the GC within their lessons it may have been a more useful measure.

8.1.1.3 Evidence of unexpected use, Use of GC out of class, Extent of use of GC - Research Area 1, Measure (c), (d) and (e)

Ann had not used a GC before her Mathematics course and it took her some time to settle into using it in place of her scientific calculator. In the first week she used the GC only once and only within her mathematics class. At the end of September Ann said that she thought she would use her GC for class work only rather than for homework and that she did not think she would find a use for her GC in her other subjects – Biology and Psychology. There is only one instance when Ann indicated, by entering an alpha code in her GC, that she was using her GC outside of the mathematics class and then it was for homework and not other subjects. This may have been an omission on her part, not indicating when she was using her GC by entering a pre-arranged code, but when comparing the quantity of data from her GC with other students in her class it indicates that she was not using her GC to the same extent as Sam and Max. It appears that Ann made only limited use of her GC and probably only during class where she had access to teacher and peer assistance when necessary. In January Ann spoke about using her GC quite considerably at the beginning of the course but that this changed due to revision for the modular examinations when GCs are not permitted. Although Ann mentioned that she used her GC frequently she mentioned that she did not use any of its special features but her use was just for the "*normal things*". Ann did show some level of independent use of her GC when during a trigonometry lesson, she realised she needed to change her calculator from radians to degrees. The teacher did not know how to make this change on her model of GC but through some investigation Ann found out for herself and taught her neighbour how to do it. During an interview Ann mentioned that she had learnt how to write messages to her friends on her GC and while this relates to unexpected use there is no evidence to support this. It can be assumed she did not write messages very often. It also indicates that Ann is perhaps not confident to use her GC in this non-mathematics way. Ann used her GC to perform mainly operations and calculations that could be performed on her scientific calculator.

David showed little evidence of unexpected use of his GC, but he did 'doodle' on his GC by pressing random keys to fill the display. David used the GC in other classes – Physics and Chemistry - and used it both at home and in class. He anticipated that he would be using the GC more as the course progressed and the data confirms his statement that he did use it in every mathematics class and for homework when necessary. There is some evidence of unprompted use when David was solving a statistical problem and he was following the procedure outlined by the teacher but there is no evidence of independent use.

Max had not previously used a GC, and initially he thought that he would use it every lesson. While he did use the GC frequently, when he faced problems with trigonometry he returned to use his scientific calculator. There were only a couple of occasions when Max used his GC in an unexpected way - to write messages to his neighbour. He used his GC for class work and homework for both Mathematics and Chemistry. Outside of the classroom he repeated previously taught procedures to resize the graph WINDOW and TRACE the curve but he also used the ZOOM feature of the GC to focus on points of interest on a curve. Max mentioned several times that he wanted to store values in his GC and although this took him some time he eventually taught himself this and used it with confidence towards the latter part of the year.

During his first interview Sam said that he would use his GC every lesson and for homework and at the end of the year he confirmed this was his approach. However there is very little Key Recorder evidence that he used his GC for homework and at times the quantity of key-stroke data during a two week period was quite limited which indicated that he did not use his GC as extensively outside the classroom as he claimed. There is some evidence to suggest that Sam explored some of the menus and functions on his GC. In one lesson he searched extensively for the numerical integration feature using the CATALOG on the GC which he had previously found and thought to be a useful feature. Sam also used his GC to write messages to his classmates. Initially Sam had used his GC to explore graphs but his unprompted use of the GC did not extend very far beyond scientific calculator features.

Sarah used the GC in many unexpected ways – she wrote messages to her classmates and explored menus and features of her GC. By following the manual in the first few weeks she taught herself how to draw polar roses and how to save and recall graphs that she had previously drawn. She also attempted to create a program with it to calculate the quadratic formula. Sarah used her GC for every subject she was studying – ICT, Biology and Physics and also for homework. Sarah said in the interviews that she used her GC less and less as the year progressed and that she found herself performing more calculations in her head. Sarah used the ENTRY and ANS keys significantly during the year and she mentioned several times how these two keys made calculations quicker and easier for her.

There is only a small amount of evidence showing Steve using his GC for unprompted work. He did suggest that he began to use it for homework after a few weeks but he eventually admitted that he had returned to use his scientific as the GC was too complicated. The only evidence of unexpected use was on only one occasion when Steve used it for writing messages to his classmate.

The majority of work the students did on their GCs during the mathematics course could have been done on a scientific calculator. The students took very little advantage of using the specific features of a GC and used it mainly as a scientific calculator. All the students explored the GC to some extent but it was only Sarah who used it for exploring an area of mathematics that was not on the AS Level Mathematics syllabus – polar graphs.

8.1.1.4 Different subject areas where the GC is used - Research Area 1, Measure (f)

The topic areas mentioned below are those that either the student mentioned in interview or their journal or if there is distinct evidence to suggest they were attempting problems within these topic areas.

During the first interview Ann mentioned that she did not think she would need her GC for her other subjects, Biology and Psychology and through the rest of the year there was no mention by Ann of using her GC within these two subjects. Ann used her GC in the mathematics class for topic areas such as trigonometry, statistics, drawing graphs and finding solutions of quadratic equations, checking answers, numerical integration, combinations and permutations and binomial sequences.

David used his GC for Physics and Chemistry as well as Mathematics. He used it for statistics, standard form, Pearson's product moment correlation coefficient, drawing graphs, trigonometry and normal distribution.

Max used his GC in his Physics and Chemistry classes. He used it for trigonometry, drawing and transforming graphs, statistics, binomial theorem, logarithms, standard form and integration.

Sam used his GC for Mathematics and Physics courses for trigonometry, the cosine rule, probability, combinations and permutations, binomial sequences, drawing graphs, numerical integration, exponential function and logarithms.

Sarah spoke often about using her GC within all her subjects – Mathematics, Further Mathematics Physics, Chemistry and ICT for both class work and homework, although during ICT she claimed that she only used it for writing messages during class time. She used it for a variety of topic areas – statistics, trigonometry, drawing and tracing graphs, standard form, probability, writing programs to calculate formulas as well as drawing and saving polar graphs.

All the students in my study used the GCs during their mathematics classes. At the beginning of the course I asked the students to type in an alpha code to signify when they used their GC in other areas e.g. Homework or Physics, Chemistry, etc. There were only a very few occasions when they entered this code and then it was usually for homework. It is difficult to ascertain when and where they used their GC so the evidence that I can rely on comes from the students' own comments during interviews and journal entries or from classroom observations. This evidence indicates that the students did not use their GC significantly during their other lessons.

This measure did not achieve its potential for collecting useful data. The students were inconsistent in providing the alpha code to indicate when and where they were using their GC. This meant that I was unable to clearly ascertain when they were using their GC – homework or other courses. The measure relied on the students to be student-researchers which in this case, was largely unsuccessful.

8.1.1.5 Frequency of use of GC with respect to other tools - Research Area 1, Measure (g)
Initially Ann mentioned that she would continue to use her scientific calculator alongside her GC until she was confident in using it and then she would rely on her GC only. Throughout the year Ann continued to mention using her scientific calculator. Although there is Key Recorder evidence to prove she is using her GC the small quantity of data does signify she was either not using a calculator at all or she was using a different calculator.

During the three interviews over the year and numerous informal chats, David stated that he used his GC everyday in place of his scientific calculator. Almost immediately he began carrying only his GC to school with him.

Initially Max said that he would carry both his scientific calculator and his GC but he would prefer to use the GC unless there was a problem. The only time he seemed to return to his scientific calculator was when he experienced problems during trigonometry and could not understand why his answer was different from his classmates. The only other instrument that he used during the mathematics course was an Excel spreadsheet and this he used only once.

During the first interview in September, one of Sam's first questions about his GC was if he could take two different calculators into the examination - his GC and his scientific calculator. He said that he would use both calculators until he was more familiar with the GC. Sam admitted that it had taken him years to become familiar with his scientific calculator and he would keep using that calculator until he gets used to the GC.

At the first meeting with Sarah she announced that she was going to put her scientific calculator away and from then only use her GC. After considering all the evidence collected from Sarah, this does seem to be confirmed. She used the GC throughout the course only putting it aside for the examinations where its use was prohibited. Sarah use of the GC changed through the course of the year. She mentioned that towards the end of the year she was using the GC less and that she was doing more calculations in her head.

For most of the students the only instruments used within the mathematics classroom were the GC and scientific calculator. The majority used their GC unless they faced a specific problem and then they reverted back to using their scientific calculator. The students from school A used a spreadsheet but this was only once during the course of the year.

8.1.1.6 Evidence of a student's succinct use of a GC with few errors - Research Area 1, Measure (h)

Throughout the year Ann made several errors on her GC, and these were mostly syntax errors. Each time Ann created an error she would either QUIT or CLEAR the error. In both cases the GC would return her to the HOME screen ready to start another calculation. Ann made little attempt to alter the incorrect entry but just deleted it in its entirety.

David created only a small number of errors during the data collection period. The majority of these were syntax errors and for the most part he would always CLEAR the error and make no attempt to alter it. Only once did he use GOTO and attempt to rectify the error and this was during the early part of the year. On one other occasion when David had entered the calculation $3 \div 0 + (0.7 \times 0.4)$ and produced the error message ERR: DIVIDE BY 0 it appeared that his response was to turn the GC off. He was unsure how to deal with the error, possibly not understanding what the message was referring to.

As the course continued Max's approach to handling errors changed. Initially he began to CLEAR the screen when an error message was generated and then he progressed to QUIT an error without altering it. Only twice Max decided to GOTO a syntax error and try to correct it. The first time was in February when he did not manage to correct the input, but he created another error and QUIT the calculation completely. The second time was in June when he altered the calculation successfully. Maybe Max was unaware that if he chose the GOTO option the GC would indicate at which point the error had been made.

Sam created several errors while using his GC. The majority of them were syntax errors, but despite the error messages, Sam used CLEAR to erase every error. He made no attempt to QUIT the error or GOTO where the GC thought there was a problem. During an early Key Recorder data file it is apparent that he tried to calculate $Cos^{-1}(467.7685185)$. It was evident that Sam did not understand the error message he had created: ERR: DOMAIN or why it had occurred. In the last Key Recorder data file Sam created a syntax error because he did not understand the difference between MINUS and NEGATIVE. His approach to dealing with error messages did not seem to develop during the 11 months of my project.

Initially Sarah experienced some problems moving around the HOME screen. She expected the GC to behave in the same way as a WP which she had used many times before. As the year progressed Sarah became more familiar with the GC and the frequency of this type of difficulty/error decreased. Sarah also encountered some difficulties when using her GC for standard form calculations. She entered a calculation as 2.35 [× 10] -12 ÷ 1.24 [× 10] -3. The GC expects a standard form calculation to be input using the [EE] key. Sarah managed to work around the difficulties by adding extra brackets but this could have been avoided by inputting the calculation as the GC expected. Sarah expected the GC to use the same syntax that she used when she wrote the calculation by hand. Throughout the year Sarah created the error message ERR: SYNTAX many times. In the first few months Sarah managed the messages by using CLEAR to erase the error and then return to the HOME screen, but as her confidence and understanding increased she began to manage the errors more successfully. She either QUIT the error or returned to the erroneous calculation and amended it successfully. There was only one occasion when Sarah appeared to have some difficulty with an error message and at that time she seemed to have some difficulties understanding the reasons behind why the error message was being produced. The error was repeated five times. She typed in ANS▶A and the error ERR: ARCHIVED was returned which indicates that the answer could not be stored to the variable A because it had previously been archived

Steve created only a few errors during his short data collection phase – the first term – and for the majority he pressed CLEAR without making an attempt to rectify the mistake within the calculation. On several occasions he made some navigational errors by trying to move around the screen as he would do when using a WP. There is also one occasion when the logical flow of key-strokes is questionable and after creating an error it appears that Steve was frustrated with the GC and he turned it off.

All the students created many different errors and the majority of them changed the way they responded to these messages over the course of this year. At the beginning of the year they were inclined to CLEAR the screen and ignore the previous error. By the end of the year many had learnt the GC would indicate where the error was if they responded with GOTO the error. From their comments on the lack of or limited training they received I had to conclude that they learnt from their own experiences how to deal with error messages and whether to correct the calculation or ignore it.

8.1.1.7 Apposite use of the GC – Research Area 1, measure (i)

All the students in the project had varying approaches for their use of their GCs. The majority of the students maintained a fairly simplistic approach to their use and frequently reduced complex calculations into multi-step simple calculations. It appeared that they were reluctant to rely on the GC to provide the correct answer. They wanted to check the GC was producing the right answers.

Sarah described how she stored values into variables in her GC at the beginning of the year and then attempted to use these values within a program she had created that calculated the quadratic formula. At the end of the year she was observed attempting a trial and improvement method to solve a quadratic equation within a differentiation problem. She had not employed the approach she had previously explored. While this is not an incorrect approach I see it as not necessarily apposite use of the GC – she was not taking full advantage of the features and facilities of the GC.

8.1.2 Research Area 2: What circumstances lead to students appropriating an instrument?

8.1.2.1 Comments from students on the advantages or perceived potential of using a GC - Research Area 2, Measure (a)

When Ann was asked in September what are the benefits of using a GC she replied that she thought it was useful for checking solutions to equations and for generally checking work. She also mentioned that her teacher had told the class it was an advantage to have a GC and that all AS Level Mathematics students should have one. This implies that Ann began using her GC without really knowing what benefits there may be, but just being aware that all students should have one. By March Ann thought the GC was "*quick, clever and efficient*" and easier to use that her scientific calculator. She mentioned that being able to view a previous calculation and then edit it was a useful feature of the GC.

David thought that the GC was much better than the scientific calculator because there was more memory and he would be able to check his answers with it. He noted that the GC had all the same features as his scientific calculator plus lots more. Initially he felt the GC was complicated and was more comfortable using his scientific calculator but as the course progressed he began to view his scientific calculator differently. After using the GC for some weeks he thought the scientific calculator was quite basic. In David's opinion the most useful features of the GC were drawing graphs and being able to TRACE a point on a graph. He also liked the statistics feature and being able to calculate two variable statistics.

Max found the most useful features of the GC were being able to view and edit previous calculations. He also commented that he found it useful for graph transformations and iteration.

After the first week of use Sam found the GC to be confusing but "*fun*" and he saw the main use of the GC was for checking his calculations. On two occasions during the year he mentioned that he found the GC helpful when the teacher was explaining something and if he did not really understand it he could turn to the GC and use that to illustrate what the teacher meant. Sam liked to be able to edit previous calculations or use a previous answer in a calculation and he made mention of these several times. It appears that he identified these as the main positive features of a GC possibly because I taught him (and all the other students) about them. Sam appeared to try and agree with me at every opportunity or tried to guess what I was focussing on and put forward an opinion that he thought closely matched mine.

Sarah found one of the greater benefits of using a GC was being able to recall and edit a previous calculation using ENTRY or using a previous answer in a new calculation using ANS. Generally Sarah had an extremely positive attitude to her GC – she liked to explore features of it and areas of mathematics that are not present in the AS Level Mathematics syllabus. She said that it helped her to work quickly and to check her answers. Sarah liked the larger display as it enabled her to look back at a previous calculation and she also stated that she found it useful to be able to type in the calculation as on paper, although this did eventually lead to some problems with standard form.

Steve liked the GC for talking to his classmates and being able to store different values under various variable names. He was confident using the GC for the scientific calculator functions and thought the GC would be useful in the future for drawing graphs. When asked how the GC might be useful Steve mentioned that it was useful because he "*needed one*", but this is the teacher's view - all AS Level Mathematics students need to have a GC. However, this is not strictly true, while the GC may be of some use and interest; the examinations are designed so that students with GCs will have no advantage over those without. Was he really aware of the benefits of using a GC?

Overall the students felt that the advantages of using a GC were that AS Level Mathematics students need a GC. They all stated that the ANS and ENTRY features were useful features of the GC as well as the graph editor. Their perception of the advantages of the GC is quite limited and seems to cover only what their teachers have expressed or what I have told them. This is not entirely surprising as the common use of their GC over the year is as a scientific calculator and only using the features as outlined above.

8.1.2.2 Comments from students on the disadvantages or perceived constraints when using a GC - Research Area 2, Measure (b)

Ann thought the main disadvantage of using the GC was being unaware of where to find the right buttons. She envisaged some confusion when she did not know which buttons to press. Ann also mentioned that it was difficult to understand mathematics topics when the teacher was unaware of which keys, or sequence of keys, to press on the GC. This was in reference to her teacher who had difficulty finding the numerical integration feature on the TI-83+. This was a problem for the three students in school A. The teacher was familiar with Sharp EL9450 GC which the rest of the class had but was unfamiliar with the TI-83+ which I had given to the three students to enable collection of the Key Recorder data. The difficulty was overcome when I explained to the students which keys needed to be pressed on the GC.

One of David's first comments about the GC was that he found it too big! He thought it would be more useful if it was smaller as it would then fit into his school bag. After using the GC for a few weeks he experienced problems with standard form. His first attempts to calculate an expression in standard form, during a Physics class, resulted in incorrect answers. He entered the standard form with an incorrect syntax but managed to work round this by entering the expression with brackets around every term. There were also some buttons on the GC – the power key and the fraction key – that were very different from the scientific calculator he had previously used. The icon on the power key was not what he expected and the fraction key was "*hidden*" away on the MATH menu. At several times over the course of the year David mentioned that he did not need to use any of the GC's features or functions, meaning that he was only using the GC as he would a scientific calculator.

Max found the GC complicated to use at first and had some trouble locating the different functions and keys. He mentioned that he found it repetitive and at times unnecessary to change the WINDOW size every time you plot a graph. His teacher had taught the class to change the size of the graph WINDOW and Max had interpreted this as being a necessity for every new graph being drawn. In a journal entry Max also wrote that he found it difficult to delete a character from a current expression. He expected it to be similar to a WP which was an instrument he was familiar with.

Sam felt that the GC had several disadvantages. He thought that there were so many buttons that it looked confusing and it was too big to fit into his school bag. In fact Sam did have a very small school bag! He mentioned that it was difficult to get started on a new topic in mathematics because he did not know where the functions or features were and the teachers were not always able to help. Sam also felt that pressing the wrong key could cause difficulties and at worst "*ruin the whole thing*".

Sarah had a very positive attitude to using the GC and found very few aspects of it to be confusing or complex. At the beginning of the year she mentioned that she thought that pressing the wrong key could be disastrous but yet there was no evidence of a disaster over the course of the year. Sarah did experience some difficulty at times locating some keys on the GC but these were soon discovered and the problem resolved.

Steve stated that he found the GC difficult when trying to find specific functions/features. He thought there were lots of buttons to press and pressing the wrong button could be quite scary.

Many of the disadvantages that the students mentioned were down to problems that they foresaw at the beginning of the year - they felt it was too big, too confusing and problematic if they could not find the right key. Many of the problems in fact did not materialise over the year, or at least not to the extent that the students first thought at the beginning of the year. Many of the students found difficulties locating a new key because they were still thinking of their scientific calculator and where the keys were on that instrument. There were some problems as the students expected the GC to respond like a WP. When they wanted to edit a previous calculation they tried to use the arrow keys to move to the previous line and make the necessary alteration.

8.1.2.3 Comments from students about the level of support or training needed and received - Research Area 2, Measure (c) and (d)

There were two occasions when Ann required help on her GC – changing radians to degrees and using the numerical integration feature. In both cases the teacher was unaware how to do this on the TI-83+ but was able to offer some help the other students in the class who had Sharp

EL9450 GCs. These were the only two instances of a need for training that Ann mentioned, although from several observations it was apparent that Ann worked closely with Sam and it is likely that they gave each other some on-going training or guidance throughout the course. Ann seemed to be more reliant on Sam for help with the mathematics and the GC but in fact they both agree it was her who found how to change the GC from radians to degree mode.

David did not refer to the manual at all during the year and seemed to be quite impressed with himself that he did not have to read the manual to get started and begin playing with the GC. There were occasions when David required some help to find a button or feature on the GC, for example - the fraction key. In these cases he asked either me or his teacher for help. Although his neighbours had similar GCs to him: TI-82 - it was a different model to the GC David used.

During the first interview in September Max said that he planned to read the manual to understand the differences between the scientific calculator and the GC. A month later at the beginning of October he contradicted himself and stated that he preferred to investigate the GC on his own rather than read the manual. Throughout the whole course there is little evidence of Max investigating his GC and in his final interview Max admits that he had not referred to the manual at all during the course. The teacher had shown the class how to use the WINDOW and TRACE features when drawing graphs but Max still needed further help. He required help to find the fraction key as well as how to change between radians and degrees. The students in Max's class had each bought a Sharp GC, as advised by their teachers. Any training the teachers gave during the lesson was based on this type of GC. If Max (Sam or Ann) had any problems with the TI-83+ GC their teachers were not able to help. I did provide help if I was asked but I decided from the beginning that I would only offer help if I was asked directly and then I would show all three students in that school.

Sam did receive some training from his teacher to resize a graph WINDOW and to TRACE a graph although there were times when the teacher was not able to help – e.g. to locate the numerical integration feature. Sam mentioned that he had used his manual to find where the factorial button was and he had also taught himself to use the CATALOG of GC features. On one other occasion his classmate, Ann, taught him to change his GC from radians to degrees.

Within the first month of use Sarah had worked through the "Getting Started" chapter of the manual to help her understand the basics. Most of difficulties Sarah faced during the year were overcome by her exploring the GC on her own or asking for help from classmates, her teachers or from me. During the final interview Sarah mentioned that her teacher did provide some instruction to use her GC to some extent but it was "*only one key at a time*".

Steve does not refer to any training or support that he was given to use the GC except that he found the manual very hard to follow.

There was only a small amount of training provided by the teachers from both schools during the course of the year. What was provided was relatively limited and in the case of the students from school A – Ann, Max and Sam – they were using different calculators to their classmates and their teacher was not familiar with the intricacies of the make and model of their GC. Sarah comments concerning the training that she received was limited and she appeared to be disappointed that there was not more significant training available to her.

8.1.2.4 Types of difficulties faced when using a GC - Research Area 2, Measure (e)

From the first interview with Ann, it was apparent that her main concern about using the GC was finding the right key at the right time. This was in fact quite a valid concern as there was considerable evidence to illustrate that she did experience navigational problems. The evidence suggests that she had problems finding the keys she wanted but also that she had problems changing from screen to screen for example - STATS editor to HOME screen. As well as this there is also evidence that Ann experienced difficulties navigating around the HOME and STATS editor screens and also altering and deleting items from these screens. The key-strokes she used indicate that she was trying to apply her knowledge and experience of how a WP works to her GC. While in the HOME screen she wanted to alter a previous calculation so pressed UP, UP, UP to return to the previous calculation to make the necessary alterations, as she would when using a WP. The GC does not work in this way and it took several attempts before Ann learnt how to successfully correct a previous error.

David experienced several difficulties with his GC – the most frequent one was when calculating standard form. He expected the GC to use the same syntax as hand-written standard form and found a key on the GC that would apparently perform the necessary calculation - $\boxed{10^x}$. This key was not the one the user is expected to use for standard form. The manual refers to $\boxed{EE}$ as the correct key. David experienced many incorrect answers to his standard form calculations and as he was convinced he needed to use the $\boxed{10^x}$ he continued with this syntax but managed to solve his dilemma by including brackets around every term. At the beginning of the year David had some difficulty navigating around the screen. He was trying to use his knowledge of WPs with the GC. When he wanted to alter a previous calculation he used the arrow keys to attempt to move around the HOME screen and make the necessary alteration. There were also some problems when David was trying to delete items from the statistics menu. However instances of both of these were only evidenced towards the beginning of the year and in the latter part of the year it was apparent that David had overcome these problems and realised the correct process for these situations.

The three main areas of difficulty for Max were navigating around the GC, navigating around the screen and handling errors. The main problems navigating around the GC were locating keys or trying to move between different screens. When Max began to use his GC for the binomial expansions he complained about the lengthy process to find and insert nCr into his calculations. Eventually he managed to find a short cut to this by using ENTRY and editing a previous calculation containing nCr. The difficulties navigating around the different screens were, on the whole, because Max expected the GC to work in the same way as a WP – insert or delete a character and alter the previous calculation. The third area of difficulty was handling errors. Max did not understand some error messages and one occasion he created the same error three times before deleting the calculation altogether. He was not confident in his interpretation of the error and as a result preferred to delete the calculation rather than alter it. Max also struggled with standard form on his GC. This was due to the fact he used the syntax of hand-written standard form and not the syntax of standard form on the GC. E.g. Max entered it onto his GC in the form 6.63 $\boxed{\times 10}$-34 ÷ 6.02 $\boxed{\times 10}$-40 and got the answer 1.1 $\times 10^{-74}$. Max knew this calculation should give a positive power but could not understand why his GC gave a different answer. His solution to this was to include brackets around everything. In fact Max made an error in assuming his syntax was identical to that of the GC, whereas the GC expected to have this calculation input as 6.63$\boxed{\text{EE}}$-34 ÷ 6.02$\boxed{\text{EE}}$-40. Although he found a way around his problem it was not the most efficient use of the GC.

The main difficulties Sam experienced were navigating round the GC or round the screen. At the beginning of the year Sam had difficulty moving between different screens and would turn the GC off in frustration and when he turned it back on it was at the HOME screen. These difficulties did seem to reduce in frequency as the course progressed.

During the first few weeks Sarah used the instruction manual to help her understand some basic aspects of the GC. She said that she was very familiar with her scientific calculator and knew where everything was and that moving to use the GC could produce problems such as locating different keys and functions. She thought she could avoid this to some extent by working through some examples from the manual. Sarah said that at first the manual seemed complicated because she did not understand which calculation it was working through. During the first few months there was evidence to suggest that Sarah was having some problems navigating round the GC, finding different keys and functions, and navigating round the screen. When she wanted to return to a previous calculation and amend it she tried to move around the screen as she would do using a WP. There also some evidence that she found it difficult to move between different screens and then back to the HOME screen. Sarah also experienced some difficulties with standard form in that she needed to include many pairs of brackets in order to calculate the correct answer. In fact she was entering the expression as she would do on paper and she was not familiar with the syntax used by the GC. Rather than use the manual to help her she found a way to solve her problem that involved alternative key-strokes – including brackets around every term.

Sarah made good use of the ANS and ENTRY features of the GC throughout the whole year and even spoke about how those two features "*make things easier and quicker*". However there was an instance when she tried to combine the two in one calculation and experienced some difficulty. When she managed to do this successfully however the answer the GC produced was incorrect as Sarah needed to include more brackets in the calculation.

Steve experienced quite a few difficulties. He found the manual hard to follow and thought the prospect of pressing a wrong key was quite daunting. He experienced problems navigating round the screen – as if he were using a WP rather than a GC. He also experienced problems finding and using the fraction key. Steve experienced problems using standard form on the GC and he found that he needed to include brackets to ensure the correct answer. This was one of the reasons he cited as being behind his decision to privilege his scientific calculator.

All the students found difficulties navigating round the GC to some extent. Many of them found difficulties switching between different screens or moving around one particular screen, but these difficulties seemed to decrease in frequency as the year progressed. To some extent all the students seemed to learn from their errors and find solutions to their problems over the course of the year. However, all the students in school B and Max from school A all mentioned problems using standard form on their GC. They all assumed that the GC would use the same syntax as hand-written calculations or maybe the same syntax as that on their previous scientific calculators. They all managed to work round this problem by including brackets in their calculation. Sarah provided an example of the type of problem they encountered:

"*I found a problem with my calculator in my Physics lesson ..., while trying to calculate* $1.6 \times 10^{-27} \div 8.5 \times 10^{-18}$ *I found the calculator was performing the calculation* $(1.6 \times 10^{-27 \div 8.5}) \times 10^{-18}$ *which means where as unlike with my scientific calculator. I now have to place brackets round values to standard form when wishing to divide them.*"

None of the students who experienced these problems appeared to refer to their manuals or ask the teacher. They all resolved this issue by including brackets around each term in the standard form equation. They had found a solution to the problem that suited them, although they all comment on how inconvenient it was to use this method. If they had entered 1.6 [EE] -27 ÷ 8.5 [EE] -18 they would have arrived at the correct answer with no need to include extra brackets. I think it is significant that they did not read the manual or ask for help from any other source to help them resolve this instead they all assumed the GC was difficult or awkward in this feature and accepted it. It seemed that they all started the year expecting the GC to be very different from their own scientific calculator and that the transition from one to the other would be very problematic. On the whole they all made the transition easily but for this particular feature they were content to continue with their long-winded and annoying solution to the problem. They allowed the GC to live up to their expectations.

8.1.2.5 Success in using a GC for problem solving Research Area 2, Measure (f)

There are two types of problem solving here – mathematical problem solving and GC problem solving. (The GC problem-solving was addressed in previous sections – 8.1.2.4 Types of difficulties faced when using a GC and 8.1.3.1 Evidence of a student's succinct use of a GC with few errors.) In this section I will focus on the students' solving mathematical problems.

Ann seemed to follow the teacher's instructions to use the GC key-stroke by key-stroke but her use of the GC outside of the classroom was fairly limited. There is evidence to suggest she did use some of the features of the GC, namely, numerical integration, drawing graphs, altering the size of the WINDOW and reviewing past calculations and answers by using the ENTRY feature but her approach to specific problems seemed in keeping with those outlined by the teacher during lessons.

When David was working on a problem where it was necessary to substitute values into a complex expression he frequently checked his calculations either by breaking them down into smaller parts or retyping calculations. Re-entering the calculations could be attributed to him sharing his GC with a classmate for some parts of the course but from classroom observations this was not a regular occurrence. There seemed to be little evidence that David used the GC for much more than a scientific calculator. David also confirmed this with some disappointment at various points over the course of the year.

Max knew he wanted to be able to store answers into variables in order to use them again in subsequent calculations. This took him quite some time to find how to do this but by the end of the course he had used it successfully. Max had also used the GC for numerical integration and using TRACE to find features of a graph, although much of this was as a comparison for his manual calculation. On the whole all the mathematical problems he encountered were solved in the way that the teachers had shown during lessons.

Sam used the GC to duplicate and confirm his own calculations. He deconstructed a fraction and calculated the numerator and denominator separately but during the interview in January it was apparent that Sam was taking the value on the GC as final without reflecting on or thinking mathematically about the answer produced by the GC.

Sarah mentioned she used her GC to confirm her answers when differentiating by examining the graphs of the equations. During the first few weeks Sarah followed an example in the manual to store values into variable names and use these variables to solve a quadratic equation using the formula: $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$. She even attempted to create a formula on the GC to save it for use later, although she was unsuccessful at this time. During a classroom observation towards the end of the year Sarah was solving quadratic equations during a lesson on differentiation. From the Key Recorder data file it was apparent that she was using the quadratic formula but was deconstructing it, evaluating it in parts and then calculating the answer using these values. She appeared to have forgotten that she had used the values in variables to calculate this at the beginning of the year.

During the first few weeks of the course, the students at school B were taught how to enter statistical data through the Stats editor and use this to find 1 or 2 variable statistics. Steve used this approach in class but when he came to use the GC at home he used the long-hand version for calculating Σx and Σx^2. He resorted to using a fairly simplistic method for these statistical calculations.

On the whole mathematical problem solving is not really in evidence from the students' work on their GC. The calculations performed by the students were simplistic and it is not possible to ascertain what type of questions they were attempting from their GC work.

8.1.2.6 Changes in a student's level of confidence when using a GC - Research Area 2, Measure (g)

At the start of the course, Ann was quite nervous about using the GC. She did not want to "*mess around*" with it and carried her scientific calculator with her until she was confident using the GC. There are several instances when she pressed CLEAR several times after each calculation, erasing the entries on the screen despite the fact she might need them later. She also checked and re-checked calculations, on one occasion more than eight times. The evidence suggested that as she found the work more challenging she started pressing CLEAR many times in between each calculation. As she became more confident with the mathematics and the GC the number of CLEAR screen reduced.

David appeared to be quite confident using his GC from the beginning of the course. He managed to use it without having to refer to the manual – which he thought was significant. He also stated that he was interested in using it for his mathematics course. There were some instances however when his level of confidence seemed in question. He repeatedly cleared the screen after every calculation which indicated that he was still focussing mainly on the GC and less on the mathematics he was using throughout the course. He also frequently confirmed his calculations by repeating them key-stroke by key-stroke or by breaking the calculation down into smaller parts. David found the GC to be frustrating when it either did not respond as he anticipated or he did not understand why it produced a certain result. He reacted to this frustration by clearing the screen multiple times. On one occasion he pressed CLEAR 31 times in total. He must have been very frustrated!

Max began the year very positive about using his GC and although this outlook was sustained for the whole year it did take some time for him to become confident enough in using the GC to refrain from carrying both calculators. By the end of the year Max had moved beyond the scientific calculator and referred to it as "*small*" and "*pathetic*". There were two instances when Max had an obvious feeling of frustration with his GC when he was unsure how to switch from screen to screen. After several attempts he switched the machine off and then on again which returned him to the HOME screen. This was only during the first few months but by the end of the course Max was using his GC confidently, with fewer instances of clearing the screen which indicates that he was concentrating more on the mathematics and less on the instrument.

At the beginning of the data collection period Sam spoke of the GC being like a "*normal calculator*" and that he was only going to carry the GC with him and would leave his scientific calculator at home. However it took several months before he arrived at this point. Within the first term Sam was observed with both calculators on his desk – almost as if the scientific calculator was there for some security for him. Sam spoke of a dislike of a messy screen which was why he kept on clearing the HOME screen but towards the end of the course the number of times he cleared the screen decreased and there was a sense that he was concentrating more on the mathematics and less on the instrument. He even stated that he preferred to see previous calculations on the screen so he can refer back to answers from preceding calculations.

From the very first interview Sarah stated that she liked all things technological and that she was looking forward to using and exploring her GC. Although she expressed some concern about pressing the wrong key and facing the prospect of not knowing how to resolve the situation, she felt confident enough to explore the GC using the manual. Within the first week Sarah had followed some of the basic examples in the "Getting Started" section of the manual. She also learnt how to save and recall graphs on her GC and taught some of her classmates to do the same. Also towards the beginning of the course Sarah experimented with creating programs on the GC and she tried to write a program to calculate the quadratic formula. As the year progressed and Sarah's confidence in her GC increased, she became more selective about when to use it. She reported that she liked to do some calculations in her head. There were some anomalies however – towards the end of the year Sarah had moved from very few occasions when she cleared the HOME screen to multiple screen clears. During one data collection session she cleared the screen anywhere from 13 times to 50 times. This was during a two week collection period. I think it is unlikely that it was shared use of the GC but that it was more likely that Sarah was doing this. There was no preceding error so it was not frustration but possibly it offered her some thinking time or a distraction from work. Maybe this had replaced chatting with her classmates?

Steve was initially wary of using the GC and initially referred to it as a "*special tool*" and spoke of it being daunting and that pressing the wrong button can be "*scary*". He used the GC to calculate complex fractions but then confirmed his answer by deconstructing the calculation into numerator (in two parts) and the denominator. He missed the opportunity to use ENTRY or INSERT features but instead preferred to delete the incorrect calculation rather than alter it. Steve's confidence in using the GC seemed to start very low and then increased a small amount but after a minor set-back – being unable to correctly use standard form and find the fraction key – his confidence began to dip again and he reported that he was returning to use his scientific calculator. For him, the benefits of using the GC were outweighed by its disadvantages.

Some of the students seemed to experience some levels of frustration with the GC, usually when they had problems moving from screen to screen e.g. moving from STATS editor to HOME screen. The most frequent solution was turning off the GC. When the GC is turned on again it presents the HOME screen – a familiar environment for the students as well as their main objective.

For all the students over the course of the year their confidence fluctuated. This seemed to manifest itself as a persistence of pressing CLEAR after each calculation or pressing CLEAR multiple times - up to 50 times in Sarah's case. This is due to the students feeling hesitant towards the mathematics as well as being sceptical about relying on their 'new' instrument - the GC. They feel uncertain about their calculation and want to keep it, and any mistakes they made, private. Relying on the GC as a new instrument takes a tremendous amount of trust when there is a lack of experience of the instrument and particularly of the mathematics. The students are in a position where they have to put their trust in a piece of new technology and hope it will provide the correct answer to their calculation. It is only through experience that the students can learn to rely on the instrument and engage with the mathematics rather than focus and worry about the GC as a tool rather than as an instrument.

8.2 Emergent Themes

Prior to analysing the data with respect to the measures, I decided to examine the data and see what themes emerged. This approach is beyond the Research Questions as set out earlier but I decided to embark on this method of analysis as it offers an alternative perspective on the data and in fact it indicated an area of interest that I had not considered when developing my research questions, for example navigation and frustration.

Initially I considered Sarah's data as an example of a complete set of data with a broad range of use over the year. After the first examination of her data, there appeared to be six main themes: Attitude to GC; Use of GC; Mathematics Work; Non-Mathematics Work; Exploring; Errors. With these themes established I embarked on a review of David and Steven's data. Almost immediately it became apparent that there were more themes than the six I had originally identified. Some of the themes needed to be sub-divided and re-named. For example I identified three further themes within Use of GC and as a consequence I divided it into themes 2, 3, 5 as listed below. The theme of Frustration emerged as I considered the reasons behind why the flow of key-strokes in Steven's key-stroke data was at times questionable. After several iterations of reading and questioning the data I identified the following thirteen themes:

1. Attitude to Technology
2. General Use
3. Frequency of Use
4. Exploring
5. Learning & Using Specific Features of GC
6. Navigating Around GC
7. Navigating Around the Screen
8. AS Level Mathematics Topics
9. Mathematics not on AS Level Mathematics Syllabus
10. Non Mathematics Work
11. Use in Other Subjects
12. Errors
13. Frustration

Below I go into these headings in detail for each of the students but due to space constraints within my thesis I concentrate on the three students from school B – David, Sarah and Steve. I chose the students from school B rather than those from school A because I thought they had a wider range of use of the GC over the course of the year.

8.2.1 David – Case Study

During classroom observations throughout the year, it appeared that David interacted with both the teacher and his classmates and was always prepared to offer an answer to a question posed by the teacher. I felt that this behaviour was 'normal' for David and was not affected for my benefit. David is a very sociable person was sometimes open to distractions from his immediate neighbours but he was also observed to be refocusing his neighbours on mathematics on some occasions.

During one lesson the students were working on probability and they were looking for the fraction key and having little luck finding it. David was the first of the three to ask for help in locating it. It appeared he was not content to sit and wait but wanted to progress with the mathematics.

Attitude to Technology Prior to the mathematics course, David had used a GC for some statistics coursework within GCSE Mathematics, and although he was familiar with the concept of the GC it was a different model from the one he used during this study. He did make note of the fact that the GC is bigger than the scientific calculator and as a result it might be difficult to fit into his school bag.

David talked of using the GC everyday and probably using it more frequently as the course progressed. He described the scientific calculator as limited and that the GC was "*lots better*" and that from quite early in the year he only took the GC to school and left the scientific calculator at home. At various times through the year in both interview and journal entries David mentioned that he found the GC quite useful although he had not used it for anything new. Every time he used the GC it was for work that could be done on a scientific calculator. It seemed that David was disappointed with the GC and that it did not live up to his expectations. In his first journal entry he wrote of his GC "*...I haven't really used it for much challenging* *stuff as of yet."*. Was he expecting a machine that would totally transform mathematics lessons and the way in which he worked?

On a daily basis David did not seem to be having any problems with the GC, although he did refer to the complication of adding brackets to everything when using standard form – something which he did not have to do when using his scientific calculator. He almost seemed to be reflecting on the 'good old days' of the scientific calculator!

During the course of the year the only time David used his scientific calculator was for the Pure Mathematics examinations, where the GC is not permitted. David mentioned that it was strange to go back to the scientific calculator and that he could remember at one time he considered the scientific calculator to be quite complicated but on reflection it looked quite basic.

General Use David made a comparison with the scientific calculator that the GC will display a decimal answer less than 1 or greater than -1 without leading zero (e.g. .756 instead of 0.756). He said that this sometimes confused him.

During his first interview David described the GC as good for checking his answers – "*you can type in an equation and it can print the answer out for you*". While his understanding of the potential of a GC may be slightly naïve, he was sure that it would help him check his answers. This understanding reflected his teacher's approach to the GC. During several classroom observations the teacher described the GC as being useful to check answers.

David described his use of the GC as developing with time and he had not experienced any disasters using the GC because he had not had time to go through all the functions of the GC. In contrast it is unlikely that David became familiar with <u>all</u> the functions of his scientific calculator during the five years he had been using it. Did he expect to become familiar with <u>every</u> function of his GC in the first term?

During the first few months of the year David persisted with clearing the screen after each calculation. David suggested the reason behind this action was that he was used to his scientific calculator only showing one line of display. He was more comfortable with his old calculator and the way he worked with it. As the year progressed David pressed CLEAR fewer times and became more comfortable with his new calculator and the way in which it worked.

There were many instances where David repeated a previous calculation after clearing the screen. He could have avoided this by not clearing the screen as often or using the ENTRY feature of displaying a previous calculation.

The Key Recorder data also illustrated that David was confirming and checking his answers by either performing one calculation and then breaking it down into smaller parts and then rebuilding the initial calculation or vice versa. While it is a valid check it also led me to consider if he trusted the GC enough to provide the right answer, alternatively he may be checking his own understanding of how the GC works.

Frequency of Use In a journal entry David wrote about using his GC regularly within mathematics and on a daily basis in and out of school. In January he said he used it during most of his mathematics lessons although Decision Mathematics, one of the modules he studied, did not really require the use of a calculator. David said that apart from the first Pure Mathematics examination the only other time he used his scientific calculator was when he was sitting at his computer and he needed to perform a basic calculation.

Exploring David mentioned that he spent the first week playing around with the GC and did not need to look at the manual at all to begin using it. There was little evidence of David exploring his GC thoroughly, although he did initially explore the DRAW menu, the LIST menu and the MATH menu within it. He also appeared to explore the TRACE feature and moving between the HOME screen and the GRAPH screen. All of this type of exploring was done quite early in the course.

There was also some exploring of how the GC dealt with lengthy calculations – as mentioned above. David deconstructed the calculations and then rebuilt them to create the required calculation to check the GC did provide the answer he wanted.

Learning & Using Specific Features of the GC There were many indicators that David had not learnt about; was not aware of; or did not want to use some features of the GC. Frequently there were instances of him using the GC to calculate parts of a calculation and then rebuilding the calculation. For example: when evaluating a fraction he calculated the numerator and the denominator separately and then rounded those answers to perform the final stage of the calculation. The result he obtained had lost a significant amount of accuracy with his rounding. He could have shortened this by using ANS, ENTRY or indeed storing the results of the numerator and denominator within variables on the GC. It is only in April that there is evidence that David had developed his use of the GC and as a result learnt to store the result of a calculation in his GC

Navigating Around the GC David's initial playing and exploring seemed to serve him well and there is very little to indicate he was struggling to find certain features of the GC. In the last interview of the year, in June, David said that he had received very little instruction from his teacher on how to find features and functions of the GC. In the first month David wanted to find STATS menu and the TESTS menu within it, instead he made an error and managed to go into the TEST menu but managed to correct himself quite quickly.

In January David reported the power key as being one feature of the GC that initially confused him. He mentioned that the icon on the GC was not what he expected. He anticipated it being the same as on his scientific calculator. In the end his teacher had to demonstrate where and what it was as he was not able to guess the correct key.

Navigating Around the Screen During the first term of use of the GC, David seemed to be having some problems navigating around the screen of his GC. He tried to alter a previous calculation by pressing UP and LEFT as can be done on a WP. There were several instances of this within the first term but he seemed to have understood the limitations of the GC in this instance and during the second and third terms there was no evidence to suggest that he was trying to move around the screen in this manner.

AS Level Mathematics Topics At the beginning of the course David says that he is not sure for which topics the GC would be useful but imagined it would be line graphs and solving equations of line graphs. Throughout the year David described his use of the GC within the following topic areas: Statistics: product moment correlation coefficient; normal distribution; linear regression; as well as trigonometry, modulus functions and graphs.

Mathematics not on AS Level Mathematics Syllabus There was no evidence to suggest that David investigated mathematics at a level higher than that present in the AS Level Mathematics syllabus.

Non-Mathematics work The only instance of non mathematical work was 'doodling' whereby David was pressing the arrow keys in order RIGHT, UP, LEFT, DOWN again and again or pressing 58585858...58 or ,,,,,,,,. He spoke about writing some messages on his GC although no evidence of this was collected, so this was quite limited.

Use in Other Subjects David was also studying Physics, Chemistry, General Studies and French and he mentioned using the GC in all subjects except French. He always spoke of using it for "*simple*" and "*basic*" calculations, probably as he would have used his scientific calculator. He encountered some problems with standard form with his GC and he found that he needed to include brackets with all his calculations which he found tedious.

Errors After every error that David made he cleared the screen, which erased the error. From the evidence gathered he did not attempt to alter his erroneous calculation or QUIT the error. Instead with every error he pressed CLEAR and returned to the HOME screen, and frequently deleted all evidence of his error by clearing the screen.

Frustration There was some evidence that David became frustrated with his GC on a couple of occasions only. When he had problems finding the correct TEST menu he pressed CLEAR 5 times which returned him to the HOME screen and cleared the screen 4 times. Excessive multiple CLEAR key-strokes was repeated on several occasions. On one occasion he pressed CLEAR 31 times after what appears to be a mis-type. Pressing it two or three times at a time might be a habit but 31 times indicates something more deliberate or conscious and possibly indicating that David was frustrated with the GC.

8.2.2 Sarah – Case Study

Sarah is a very pleasant and friendly individual but during class she was very quiet. She frequently sat on her own and appeared to work hard during the entirety of the course. On many occasions Sarah was asked by her immediate neighbours to clarify some of the mathematics being explained by the teacher and her neighbours were always interested to see her solutions to the problems that were set.

Attitude to Technology During all interviews or informal chats, Sarah mentioned that she had a great love of all things technological. During the first interview with her she said "*Technology is one of my favourite things.*" This attitude seemed to remain for the duration of the year. She appeared to be very positive towards her GC and was very pleased to replace her scientific calculator. She described her first week with the GC as "*..fun...*" and that she has found it "*very useful... very easy to learn...*" and that she is "*...looking forward to learning more...*". In one journal entry Sarah even stated that she would take her GC with her on holiday so she can keep practising.

Sarah used her GC within Mathematics, Biology, Physics and ICT classes to varying degrees and in a variety of ways. She frequently talked about using the GC to write messages to her friends during the ICT classes. In a journal entry later in the year, Sarah wrote that she used the GC for writing messages to her class mates and that although the novelty of the GC may be wearing off she still found it more useful than her scientific calculator.

General Use Sarah's teacher referred to the GC's main use as being as a "*checker*" and this seems to have been echoed by Sarah at various times during the year. It is not possible to determine if this is a result of the teacher's positioning of the GC or this is due to Sarah's own perceptions of the GC. She described the GC as an instrument to check calculations within a journal entry and also when she was discussing how she used her GC during the course of a lesson. She referred to using the GC to check answers to "*larger sums*". Sarah only seemed to relate to the GC as a checker for when she was calculating sums and not as a checker using an alternative method. For example, she referred to it as a checker for a sum $\sqrt{(41.5)}$ but not for using it with the quadratic formula or drawing a graph to check the solutions to her quadratic equations. Was Sarah influenced by the teacher's comments or would she still have used it in this way despite how the GC was referred to by the teacher?

Frequency of Use The evidence collected indicates that Sarah used her GC a great deal at the beginning of the year but as the year progressed she used it more selectively. During the last interview in July, Sarah described her use of the GC as changing over the year. She mentioned that as the year went on she was undertaking more calculations in her head. A few of her journal entries made note of the fact that she was not using her GC as much because some calculations were easier to do in her head than using her GC. She also wrote that the novelty of using her GC for writing messages to her classmates during lessons was wearing off.

Exploring Although Sarah mentions in the July interview that she did not use the instruction manual for the GC very much, I consider this to be a contradiction. During the first interview and the first few journal entries Sarah referred to using the manual. She even mentioned that reading the manual helped her see the potential of the GC. In particular Sarah used the manual for providing instructions for drawing polar roses and polar stars and saving them to recall later. She also altered the equations she had previously entered and drew her own polar graphs. (See Figures 8.1 and 8.2) At times Sarah also worked independently of the manual. She stored numbers into her GC and then entered the quadratic formula. Although an example of this type is in the manual, Sarah used different coefficients when she attempted it. There is no evidence to suggest she used the same example from the manual as a trial.

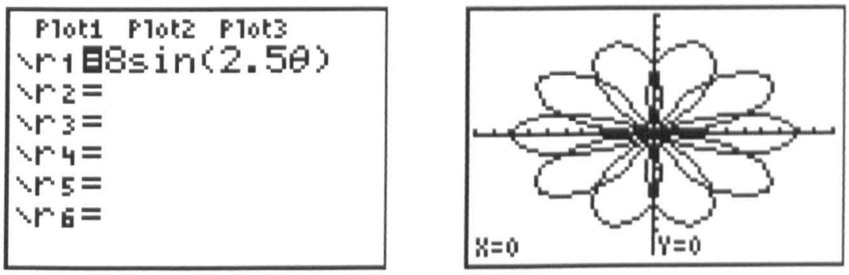


Figure 8.1 Sarah Drawing Polar Rose

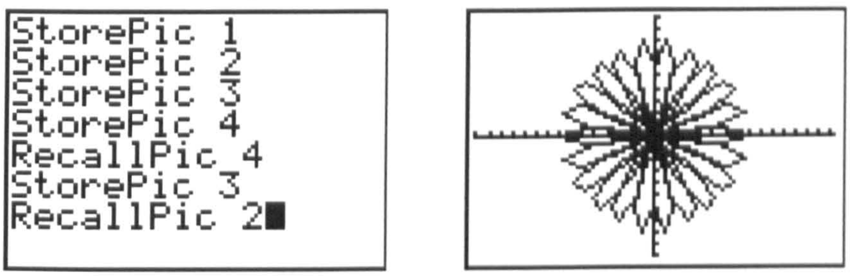


Figure 8.2 Sarah Storing and Recalling Polar Graphs

This is only a small independent step; however, Sarah also tried to save this formula as a program within her GC. Although she was unsuccessful, this example does not appear in the instruction manual. This provides evidence that she is aware of some of the potential of her GC (from reading the manual or otherwise) and used it to explore with her own needs in mind.

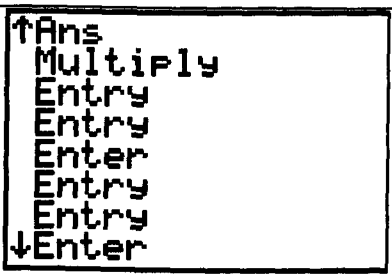
When Sarah was asked if she had received any other help to use her GC, she said that she had not, although the teacher had from time to time referred to a different function or feature of the GC but "*They would teach us all and even then only one button at a time*". This appeared to suggest that Sarah was disappointed that the GC was not used further and in more depth and that the use in class was quite superficial, almost as a scientific calculator.

Learning & Using Specific Features of GC At the beginning of the year Sarah compared the GC with the scientific calculator and referred to the difficulty in becoming used to the GC after using the scientific calculator for so long. By the end of the year Sarah again compared the two calculators in light of the examinations but this time said that she said had forgotten where everything was on the scientific calculator and had to take time getting used to it again.

Sarah used the manual to learn how to create, save and recall polar graphs; used variables with formulae and attempted to save the formula as a program, albeit unsuccessfully. The majority of this was during the first few weeks of receiving her GC, however towards the end of data collection Sarah was observed during a lesson on finding maxima and minima with differentiation and she repeatedly used a trial and improvement method to find the solutions to a quadratic. She appeared to have forgotten that she had previously stored coefficient values in variables A, B and C and used these with the quadratic formula.

During a lesson on probability, Sarah and David were unable to find how to convert decimals into fractions on their GC. Their GCs were a different model to those used by the rest of the class. David asked the teacher, who was unable to help and then he asked me. Sarah did neither and it was only at the end of the class, during an informal chat that Sarah admitted that she did not know how to do it. I demonstrated how it could be done and from then on she appeared to use it without problem.

Sarah made good use of the ANS and ENTRY functions of the GC and not only did she use them individually but she combined them and embedded the ANS function within a calculation. (See Figure 8.3)

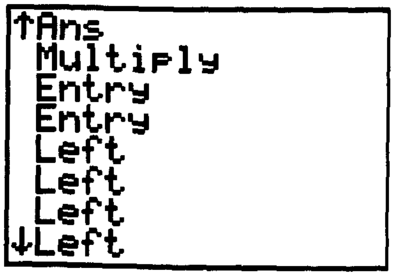


Sarah attempts to multiply her previous answer with a previous entry unsuccessfully.

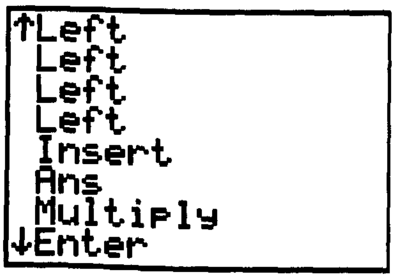
She aims for
ANS × ENTRY
ANS × 39771 – ((679)² ÷ 15) = 9034.933333
But only achieves
39771 – ((679)² ÷ 15) = 9034.933333

The previous entry overwrites ANS ×

Again Sarah tries to multiply her previous answer with a previous entry, with the same lack of success.



Left 17 times in total



Sarah achieved some level of success by taking the previous entry and inserting her previous answer at the beginning. To make this calculation mathematically accurate Sarah would need to include extra brackets around the previous entry.

Figure 8.3 Sarah Manages to Embed ANS within a Calculation

The data collected from the other students in the project shows that this was not standard practice and Sarah seemed to be the only student, of the 5 who I followed and completed the course, who embedded it within a calculation. She initially found it difficult and attempted it several times before she succeeded. In fact there was only Max who attempted anything comparable. He stored the answers from the previous calculations as values within the variables A and B and then proceeded to make the final calculation using both these values. Although Max's calculation was more successful than Sarah's, I see Sarah's use as a way of more fully understanding the constraints and potential of the GC.

Navigating Around the GC At the beginning of the year Sarah spoke about frequently pressing the wrong button on her GC because she expected it to be similar to her scientific calculator. She tried to transfer her knowledge of using her scientific calculator to the GC. Throughout the year there seems little evidence of Sarah being 'lost' within her GC or trying to find a function, although in the last interview she did talk about the problems she had finding the modulus key and the fraction key.

Initially there seemed to be some indication that Sarah was exploring her GC by scrolling through some of the different menus. There was also some evidence of Sarah apparently struggling to exit the STATS menu and return to the HOME screen. While Key Recorder does not indicate when the GC was turned off, the logical flow of key-strokes is questionable and therefore indicated that the GC was turned off, maybe through frustration at being unable to exit a menu successfully. This type of activity decreased in frequency as the year went on which may indicate that Sarah felt more confident about where certain functions were located.

Navigating Around the Screen Although Sarah did not mention it in interview or discussion, the list of key-strokes from the GC on several occasions does indicate that she was trying to move around the screen unsuccessfully. It suggests that Sarah was trying to transfer her knowledge of WPs to her GC. After completing an entry Sarah tried to edit the calculation by moving left several times which on a WP would allow her to edit the previous line but on the GC this is not possible. There were several instances of this within the first few weeks of receiving the GC although it did decrease in frequency as the year went on.

AS Level Mathematics Topics Sarah used the GC for the whole of her mathematics course – Pure Mathematics, Statistics and Decision Mathematics. Although the GC was available for her to use throughout the year Sarah only referred to a few mathematics topics during her interviews and journal entries – probability, trigonometry (degrees to radians), indices calculations, and statistics with one and two variables.

Mathematics not on AS Level Mathematics Syllabus Sarah used her GC several times for mathematics that was not part of the AS Level Mathematics curriculum. The main area was polar graphs which she stated she found really interesting and liked to show off these graphs to her friends. From reading the manual Sarah taught herself to draw, save and recall polar stars and polar roses. At the beginning of the year, when her GC was still new to her, Sarah used it to store values into variables and then use these values within a formula. She tried to store the formula as a program within the GC but did not succeed. Although solving quadratics using the formula is part of the curriculum, storing the formula as a program is not and Sarah attempted this independent of her teacher.

Non Mathematics work Sarah frequently used the GC for writing messages to her class mates. She spoke about it during interviews and the evidence was there within the list of key-strokes. Sarah said the reason she "*chatted*" with her neighbour was that the ICT lessons were "*boring*". She referred to the novelty of writing messages having worn off as the year progressed but there was still evidence of this even at the end of the year.

Use in Other Subjects At the beginning of the project I asked all the students to indicate on their GC when they were using their GC outside of the mathematics classroom, either at home or within other classes. Unfortunately for the majority of the time they forgot and so it is difficult to determine when they are using the GC. Sarah mentioned during interviews and discussions that she used her GC within her other courses – Biology, Physics and ICT although in ICT she used it mainly for "*chatting*".

Errors There are many instances where Sarah made errors while using her GC. Most of these were syntax errors. The majority of the errors were cleared and deleted but very few were amended. Sarah would rather rewrite the whole calculation again rather than try and correct it, even though the GC will usually indicate where the error lies within the calculation.

8.2.3 Steve – Case Study

Steve was a very eager volunteer for my study but during the data collection he seemed very shy and reserved with me. During the first term Steve only made 2 journal entries and both were very limited and were both produced after repeated requests.

Steve spent the lessons I observed being very chatty and distracting those around him. He gave the appearance of somebody who did not understand the topics and would rather ignore them than try and work at understanding it. His distracting behaviour included pressing keys on his neighbour's GC while he was trying to work. Steve seemed to rely on David to explain again when he did not understand the topic or was distracted during the teacher's explanation. Steve seemed very reluctant to speak to me and I saw this as his reluctance to discuss mathematics that he found difficult. Steve made a comment about the vast amount of work another student (Sarah) from the project was doing on her GC. On reflection it seemed to be a comment driven by jealousy that the other student understood the mathematics more than he did.

After the Christmas break Steve left school B and all the courses he was enrolled on. He told school he was embarking on a training course. The Head of Mathematics told me that prior to the Christmas break Steve took part in a Mathematics Challenge at school and was in the top few students who completed the challenge. The Head of Mathematics also said he thought Steve had an aptitude for mathematics but was lacking in application.

Attitude to Technology Through the interviews with Steve it became apparent that he was very cautious about using the GC and at times it came across as lacking enthusiasm to use it. During the first interview he described using his GC as "*ok... fine...scary at first*". Also during this interview Steve stated that he viewed a GC as being quite useful but "*when you make a mistake it is quite scary*". He mentioned that he did not want "*to risk using the GC in other classes*" because it was a special piece of equipment. The words he used to describe this are quite interesting. What risk did he foresee - a risk to the GC itself or a risk to his understanding? He further described the GC as being like a basic calculator but "*very advanced*" and that it was a more advanced instrument for harder mathematics.

Steve also talked about "*needing*" to have a GC for his mathematics course – perhaps a decision he was not in favour of? From this it appears that he feels he was being pushed into using a GC and he was not entirely confident in using it. However Steve also questions the ability of the scientific calculator to cope with the mathematics and asks if it has the right functions and if it can handle the data?

A couple of months into the course it is evident from a journal entry that Steve is still using his scientific calculator as well as the GC. He describes the GC as "*different and difficult*" and that he was using it less and less and returning to use his scientific calculator. He also stated "*it's quite scary*" when he presses the wrong button.

General Use Steve used his GC to write messages to his neighbour in class. There is also evidence that he checked some calculations with his GC when he entered the complete calculation for standard deviation and then broke it down into the numerator and two parts of the denominator in order to check it. Although Steve stated that GCs are used for advanced mathematics he used it for very simple calculations and on occasion too simple (i.e. $1 + 2 = 3$). Conversely he was obviously more comfortable with his scientific calculator but chose to use the GC for simple calculations and simple trigonometry.

Frequency of Use Initially Steve mentioned that he would use GC at school and scientific calculator at home but towards the end of the first term he mentioned that he found the GC too difficult to use and then returned to the scientific calculator. The quantity of Key Recorder data collected confirms his statement.

Exploring Steve stated that he found it too complicated to draw graphs with his GC. He did try to follow the manual but found it was '*...impossible to read because there was too much* [information] *there...*'. A couple of weeks later Steve used his GC to draw several graphs: $y = 10$ and $y = -10$. These are not found in the manual and were not part of the lesson. Was he investigating the graphs or investigating the GC? Due to his previous statement it can be seen that he was taking small steps to explore the graph drawing feature of the GC. Towards the end of the first term Steve was again exploring the graph editor on the GC. He entered the equations $y = 1, y = -1, y = 2, y = -2$ ... and displayed them. He then deleted these graphs and entered $y = x$, $y = 1x$, $y = 2x$, $y = 3x$ ... and again displayed them. All these graphs should be explored at GCSE level either Intermediate or Advanced Level. What does this say about his understanding of coefficients? ($y = x$ and $y = 1x$) Steve was either 'doodling' or had not at that point grasped a basic understanding of graphs and gradients. Steve also talked about having difficult locating several keys on his GC – fraction key and π – and he said that it was easier on his scientific calculator because he knew where the keys were.

Learning and Using Specific Features of GC There is only a small amount of evidence that Steve used specific features of his GC. He stated that he found it difficult to enter graphs as examples from the manual as he found the manual complicated. Steve found the GC straightforward to use for basic calculations. Although he seemed impressed that the GC could store many values there is no evidence to suggest that he used this feature at any time. He also seemed to be missing the opportunity to use shortcuts or specific features – he used DEL several times to erase an entry rather than CLEAR and he did not use INS or ENTRY. Apart for drawing some graphs Steve did seem to be using his GC as a scientific calculator and he did not seem to incorporate any of the specific features of the GC in his work.

Navigating Around the GC Steve makes a comparison to his scientific calculator and wrote that his GC is not as straightforward because there are several keys that he is unable to find – fraction and π.

Navigating Around the Screen Steve showed some lack of understanding about how to move around the screen when he tried to alter a previous calculation by using UP, LEFT, DEL ... He also tried to move around the graph editor screen with some difficulty. Both of these instances illustrate that he was trying to transfer his knowledge of the WP onto his GC.

AS Level Mathematics Topics Steve used the GC to help with drawing linear graphs, standard form, trigonometry and statistical calculations.

Mathematics not on AS Level Mathematics Syllabus Steve was seen to only investigate mathematics that was on the syllabus.

Non Mathematics work During the first interview Steve spoke about how he used the GC to write messages to a classmate. Although Steve did not continue through the whole mathematics course he did stay for one term and during this time there is no evidence to show that he wrote any messages on his GC.

Use in Other Subjects Steve stated in an interview that he anticipated he would not use the GC in other subjects because he felt that it was "*special*" equipment. It seemed his concern here is that he did not want to damage the GC during another lesson but I think this was an attempt to obscure another concern, namely that he was not confident in navigating around his GC.

Errors When Steve created an error message on his GC he pressed CLEAR to delete the error message; switched off the GC with no attempt to amend the error; or on only one occasion he responded GOTO which took him to the calculation and indicated where the error could be found. This does not seem in keeping with the way other students deal with their error messages. Although the evidence is limited there is enough to suggest that on the whole Steve was avoiding the error messages by either erasing the message or turning the GC off.

Frustration On several instances it appeared that Steve was struggling to exit one screen or had created an error and did not know how to alter it. Although the GC did not record it, it seems certain that he turned his GC off, possibly in frustration. He did not learn how to operate his GC but resorted to turning his GC off – a fairly drastic solution.

Chapter 9 Discussion of Research Questions

This chapter revisits the research questions I devised and considers them in the light of the data collected. I consider each research question in turn and reflect upon it in light of the data. (The references back to the data are made with respect to the data ascribed to the different measures for each student as found in Chapter 7 Results. For example, the first reference below is for Sarah – measure 1b, Obs1. This references *measure 1b: Student reponses to teacher's prompts to use GC* back to Sarah's results and can be found in Observation 1 (see page 62). The abbreviations I use within this chapter are outlined in Table 7.1, Abbreviations of Data Sources.)

9.1 Research Area 1: *What is appropriation of technology and how does it manifest itself?*

RQ1a. ***Can appropriation be described in terms of (i) unprompted use and (ii) own strategies?***
I previously defined 'unprompted use' as a student using their GC to follow procedures set out by the teacher but without instruction from either the teacher or their peers. I consider that 'own strategies' is when a student is developing their own methods on the GC for solving problems already encountered within the mathematics class. Students who use their GC without external prompts have sufficient understanding of the procedures to use them without support and possess a level of confidence in their skills to embark on work independent of instruction. I see that this is an indicator that the student is making headway towards appropriation.

There were many occasions when Sarah worked without instruction from the teacher outside the classroom (measure 1b, Obs1; measure 1d, KeyR1; measure 1e, KeyR2) and there were also instances when she began entering data and performing calculations before the teacher had issued instructions to the class (measure 1b, Obs1). Max was observed working unprompted to resize the graph WINDOW several times through a lesson (measure 1d, KeyR2; measure 1i, KeyR1). He was successful at this although at a later time he commented on that he thought it was "*quite annoying*" to change the WINDOW every time he drew a new graph (measure 2b, Jrnl2). Alternatively, a student may only use the GC to perform certain procedures if support is present. For example, Ann followed teacher instructions successfully during the lesson to resize the graph WINDOW (measure 1b, KeyR1) but after thoroughly analysing of her Key Recorder data of GC use outside the classroom, there was no evidence to suggest that she attempted this procedure without direct instruction from her teacher. There little evidence of the students using their own strategies to problem-solve. It was only Sarah who attempted this when she tried to store values in the GC and use them within the quadratic formula (measure 1c,1d KeyR1) but she was not successful in this and there was no evidence to suggest she perfected this procedure later. Max only marginally used his own strategy when he stored values on his GC to use later (measure 1e, Jrnl5). The other students seemed to make no attempt to identify their own strategies for problem-solving.

All of these instances indicate that some level of confidence to use the GC for a specific task is essential as well as the ability to use the GC correctly. As mentioned in section 9.3.1 Stages of Appropriation, David, Max and Sarah were moving towards appropriation but Ann and Sam experienced some levels of conflict and found these difficult to overcome and therefore they were making only very slow progress along the path to appropriation.

Appropriation is more than just unprompted use of a GC or using one's own strategies with a GC but these are both good indicators of a student beginning to appropriate their GC, as they indicate a confidence in their own skills and use of procedures on the GC.

RQ1b. ***Does appropriation manifest itself in consistent ways among individuals and if not, how does it vary?***

The definition of appropriation I have assumed includes the sense of ownership, mastery of some aspects of the GC, taking it for one's own intention as well as the concept of instrumental genesis. While all the students did not achieve each of these states to the same extent there are some similarities and consistencies in the evidence from the students who are moving towards appropriation – writing messages to friends, overcoming syntax issues, frequency and level of use, the manner with which errors are dealt. Sam and Ann from School A both used the GC in similar ways. They relied on both the scientific calculator and the GC for significant periods at the beginning of the year (Ann – measure 1a, KeyR1; measure 1d, KeyR1, KeyR2; measure 1e, Int1; Sam – measure 1a, Obs1, Int1; measure 1e, Int1). However there are some differences between students – particularly the way in which Sarah used her GC. She explored her GC more, using both the manual and pressing keys to see where menus would lead (measure 1c, Int1, KeyR2; measure 1d, Int1). She attempted to use the GC for her own needs when she attempted to store the quadratic formula as a program (measure 1c,1e, KeyR1) and when she tried to combine ANS and ENTRY within a calculation on the HOME screen (measure 1i, ObsKr1).

Appropriation does differ between individuals – the exact differences are difficult to identify as the number of students in my study was small and all the students were at different stages of appropriation. There are some similarities but the degree to which each of these similarities exists depends on what stage of appropriation they are and what level of resistance is present.

9.2 Research Area 2: *What circumstances lead to students appropriating an instrument?*

RQ2a. What enablements are there to a student appropriating an instrument?

Each individual will appropriate a GC to a different extent and at different speeds. This can be attributed to previous experiences of the student with mathematics, technology, the teacher etc. There are some factors that could enable a student to progress towards appropriating their GC: an interest in and attitude towards technology; a sense of ownership of GC; placing their own intention or meaning on the GC. Lagrange (1996) in his survey of pupils' attitudes when using CAS in the classroom says there are three necessary conditions for the pupils to use CAS:

- good understanding of the affordances and strengths of using the CAS;
- ease of use of the CAS;
- "*...a personal relationship with [the tool] seems to be essential ... to help pupils to understand and learn mathematics*."(p.105)

While he does not use the term 'appropriation' he does appear to be describing some of the characteristics of appropriation.

It is also important that the students understand the affordances of using the GC. Ann and Steve both state that they were advised by their mathematics teacher to acquire a GC for their mathematics course because it would be helpful (Ann – measure 2a, Int1; Steve – measure 2a, Int1). They did not expand on this and neither student was able to cite any benefits to using the GC other than just being told by the teacher. These two students did not develop a strong sense of ownership of the GC. They were encouraged to buy one but were not made aware of its potential. Sarah on the other hand was confident in using her GC (measure 2g, Int1, Jrnl2, Int2) and explored it thoroughly, particularly at the beginning of the year (measure 2g, Int1, Jrnl1, Jrnl2, Int2).

The role of the teacher can also have a significant effect on the student's level of appropriation of the GC. With the use of GCs in the classroom the teacher role will be transformed and they will take on the role of technical consultant and provide training on this new tool when necessary. All the students in my study experienced difficulties with their GCs to some degree (David – measure 2b, Jrnl3; measure 2c, Obs1; measure 2e, ObsHR1; Sarah – measure 2b, Jrnl1; measure 2e, ObsKR1, Int2, Int3; Steve – measure 2e, Int1, Jrnl2, ObsStRKR1). The students in school A, Ann, Max and Sam, had greater difficulties than those from school B as the type of GC given to them (TI-83+) was an entirely different make and model to that which the other students in their class used (Sharp EL9450). The teacher was not able to help if the students experienced difficulties and any training given in class was applicable only to the Sharp model (Ann – measure 2b, Jrnl2; measure 2c, Obs2 p2; measure 2d, StRcl1; Max– measure 1b, ObsKR3; measure 2c, ObsStRclKR1; measure 2d, Int3; Sam – measure 2b, 2d, Int3; measure 2c, Obs3;).

From my study it is not possible to definitively state what factors would encourage a student to appropriate a GC, however it is evident that all the students held a negative view of the limited training to use the new tool that was provided by the teachers. It also seemed apparent that the students who were unsure as to the benefits of learning to use the new tool were those that did not appropriate their GC.

RQ2b. ***What obstacles are there to a student appropriating an instrument?***

There are potentially several obstacles to a student appropriating a piece of technology, some of which are discussed more fully in 9.3.3 Barriers to Appropriation but in brief, some of the obstacles the students in my study experienced were:

- problems associated with changing from an old an familiar tool to a new tool, Ann – measure 2b, Int1; measure 2e, KeyR2; David – measure 2b, Jrnl3, Int2; Max – measure 2c 2e, Int1; Sam – measure 2d, ObsKR1; Sarah – measure 2b, Int1; measure 2c, Int2; measure 2e, ObsKR1; Steve – measure 2b, Jrnl2

- the institution or environment within which the student was using a GC,
  Ann – measure 1b, 2a, 2g Int1; David – measure 2b, Int2; Max – measure 1b, Int3; Sarah – measure 2b, Int3; Steve – measure 2a, Int1
- the design of the current curriculum which restricts use of GCs within examinations
  Ann – measure 2a, Int2; Sarah – measure 2b, 2c, Jrnl1;
- disappointment experienced by students as the GC failed to live up to their expectations
  David – measure 2b, Jrnl3, Int2; measure 2g, Jrnl1; Sam – measure 2b, Jrnl2; Steve – measure 2e, Jrnl2
- frustration as a result of problems encountered using their GC
  Ann – measure 2e, ObsStRcl1; Max – measure 2g, KeyR3; Sam – measure 2g, KeyR4; Sarah – measure 2g, KeyR3; Steve – measure 2e, ObsKR1

9.3 Appropriation

This chapter considers appropriation more fully and discusses at what stages of appropriation the students found themselves at the end of the year; the journey taken towards appropriation as evidenced by one student; the barriers to appropriation the six students experienced.

In Chapter 1 I considered several definitions of appropriation and outline my own definition. To recap in brief, I perceive appropriation in terms of Wertsch's sense of ownership of the tool along with mastery of the tool, combined with Guin and Trouche's concept of instrumental genesis – the transformation of a tool into an instrument. It is apparent from analysing all the students' data that by the end of the year none of the students had mastered every aspect of their GC and its functions. Considering the definition of appropriation with regard to each of the students enables me to comment on which student has or has not begun to appropriate their GC.

My initial thoughts were that appropriation can be considered as a continuum with appropriation at one end with complete lack of appropriation towards the other and I placed each of the six students on the continuum as follows:

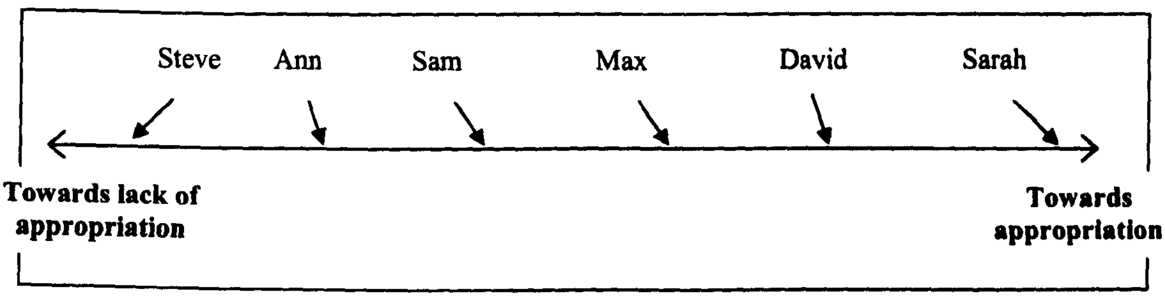


Figure 9.1 Students on the Appropriation Continuum

The gradient of the arrows illustrates the individual's progress towards appropriation. Sarah is moving towards appropriation at a greater rate that the other students and Steve is moving towards lack of appropriation after initially making some progress towards appropriation.

However, this diagram does not reflect the multitude of factors that may influence a student as he/she learns to use a GC and move towards appropriation. This makes appropriation a multidimensional concept with each factor having the potential to affect each individual to varying degrees which can result in differing levels of appropriation. After considerable reflection and thought I believe the main influences on the students in my study are: the teacher, tension between the old tool and the new tool, the institution, the curriculum, personal aspirations. Each of these will influence each student to different degrees. Some factors will positively influence one student whilst having a negative influence on another. Within the next three sections (9.1 Stages of Appropriation, 9.2 Moving Towards Appropriation and 9.3 Barriers to Appropriation) I will expand on these factors and consider how they may have influenced the students in my study.

9.3.1 Stages of Appropriation

All the students, except Steve, were moving towards appropriation and mastery, albeit at different rates, but it was only Steve who seemed to be moving away from appropriating his GC in any definite way. He showed very little appropriation of his GC during his three months on the mathematics course (more details below) and created some barriers to appropriation (see section 9.3). He appeared to be using the GC because he was told to use it by his teachers rather than believing it would help him with his studies. Also there was no evidence to indicate that he had any enthusiasm for this new instrument. Initially he spoke of being scared of what would happen if he pressed the wrong key or of using it in his physics lessons. He also said the GC was so special he was only going to use it for mathematics and not for any other course (e.g. Physics). He was reifying it as a special tool by restricting his use of it.

During the first few weeks of use Steve mentioned that he was using his scientific calculator as well as his GC but as he became familiar with the GC he began to use that calculator more. His confidence in using the GC increased and he spoke of how it became easier to use. However it was after he experienced some problems with finding the fraction key and encountering incorrect answers with standard form that this seemed to change. He thought the scientific calculator was more reliable and talked of reverting to this instrument for his Mathematics and Physics lessons. Because Steve withdrew from the AS Level programme at Christmas it is not possible to gauge how his use of the GC may have changed over the rest of the year. The plans he was making to leave may have influenced his change of opinion of the GC. If he knew he was leaving there was no need to continue to try and learn the intricacies of his GC.

There were great levels of resistance for Steve as he used the GC. He thought that the GC was complicated to use and he did not perceive any benefits to using it. Throughout the year he experienced difficulties in using the GC. This level of resistance rose to such high levels that he talked about returning to use his scientific calculator and the evidence available seems to confirm this. Wertsch (1999) writes that appropriation involves mastery and ownership of the tool. He considers that there is likely to be some level of resistance between the agent and the tool and if it reaches high levels, it may result in restricted use of the tool or complete avoidance of the tool. Steve's experiences with the GC seem to epitomize this description of the result of a high level of tension between the agent and tool. Guin and Trouche's definition of appropriation describes it as having two sections – instrumentation, directed towards the artefact, and instrumentalization, directed towards an outside context. Steve seemed to be having problems with both of these areas. The GC did not transform into an instrument for Steve as he encountered problems learning how to use the tool effectively and he had not appreciated the potential of the tool as a problem-solving instrument. He seemed to make some small steps towards appropriation but after some setbacks he began to move away from appropriation. He perceived it as a special tool with inherent difficulties, and possibly by reifying it, it lived up to his expectations.

Ann and Sam were similar in their attitudes to using their GC. Both spoke of using their scientific calculator early in the year, almost as a 'back-up' to the GC. Sam thought the GC was too big and was observed with both his scientific calculator and GC on his desk at the same time. The scientific calculator was almost a security system that Sam could reach for if he had difficulties with the GC. As the course progressed both students talked of using their GC instead of the scientific calculator but after analysis of the Key Recorder data and reflections on classroom observations it was apparent that they were not using their GC in the manner they stated. They both found the mathematics course challenging and this may account for the limited use of the GC. They were familiar with the scientific calculator and since the majority of their use of the GC were the features available on the scientific calculator it is not surprising that they chose to privilege that tool instead. Ann and Sam did make some attempts to explore their GCs but were reluctant to leave their scientific calculators behind and rely entirely on the GC. Considering Wertsch's concept of appropriation - their levels of ownership and mastery of the GC were very limited and the tension between both the two students and their GCs was comparable. Although they had made some move towards appropriation of the GC they had really only appropriated the scientific calculator features of the GC. It appears that, like Steve, they found difficulties in perceiving the benefits of the GC. Again, as with Steve, there was the tension between the old tool (scientific calculator) and the new tool (GC) and initially both Ann and Sam were inclined to rely on their scientific calculators more than their GCs. By the end of their mathematics course they had not taken ownership of the GC or mastered any significant features of the GC. Their use of the GC did not indicate instrumentation as they were disinclined to rely on the GC and continued to use their scientific calculators. Neither did their use indicate instrumentalization, in my use of the term (see p.6), as they were unable to appreciate the full benefits of the GC and they had not experienced it developing into a problem solving instrument.

Max and David achieved similar levels of appropriation. Both students experienced problems with standard form and Max encountered problems discovering how to change the mode from radians to degrees, but both overcame these problems and despite them, were eager to use the

GC for all their AS Level courses. By the end of the year they were both using the GC instead of the scientific calculator and had mastered various techniques on the GC. The levels of ownership experienced by these two were relatively high in spite of the set-backs and although they did not appropriate the GC entirely there were some elements of the GC that they did come to appropriate. They privileged this piece of technology and their confidence developed when using it. They had begun the process of instrumentation but there was little indication that they perceived it as a problem-solving instrument and therefore they did not experience instrumentalization, in my use of the term, of the GC.

Sarah was the student closest to appropriation of the GC and seemed to be moving closer towards appropriation as time progressed. She had mastered some functions and features of the GC, although not all, and was eager and confident in using it. From the start of my study Sarah expressed her enthusiasm for technology and was eager to explore her GC and determine its potential. She exemplified the concept of appropriation as outlined by Wertsch and had begun her journey towards instrumental genesis as defined by Guin and Trouche (1999). She had become familiar with the some of the technicalities of the tool and had become a confident user of the GC. Sarah had explored the GC and was able to perceive the potential and constraints of the GC and she had begun to select it as a problem-solving tool when she deemed it relevant. This indicates that to some extent Sarah experienced instrumentation and instrumentalization, in my use of the term, of her GC.

All six students had different experiences and held differing attitudes towards using the GC for mathematical problem-solving and consequently they appropriated it to varying degrees.

9.3.2 Moving towards Appropriation

Evidence collected from Sarah indicated that she was moving towards appropriating her GC faster than the other students in the project. She began the year talking about how she enjoyed playing around with anything technological. Sarah had even set up a web-site with a friend.

Sarah's journey towards appropriation has much in common with Guin and Trouche's (1999) characterisation of instrumental genesis. They describe two distinct phases of instrumental genesis as the discovery phase and the organisation phase. In the *discovery* phase a student will realise the effects and organisation of various commands and will show a high dependence on the calculator. Sarah had definitely entered this phase. Her level of use of the GC during the first few months of the course was more substantial than the other students in the project. During the first few weeks Sarah referred to the manual, for not just "Getting Started" but to explore some of the GC's potential. She was intrigued by some of the graphs within the manual and followed the instructions to draw, store and recall these graphs. Sarah found instructions in the manual to write programs and she attempted to create a program that calculated the quadratic formula so she could store it for future use. She also used the GC for writing messages and for problem solving. Sarah was keen to explore the potential of her GC and even spoke of taking the GC on holiday with her so she had further opportunities to play with it!

In Guin & Trouche's *organisation* phase the student becomes aware of the potential and constraints of the calculator and begins to be more selective about their use it. This also describes Sarah's use of the GC over the year quite succinctly. As the year progressed Sarah's use of the GC changed in this manner and she began to use it more selectively. In the final interview Sarah described how she found that some work on the GC became quite lengthy and was inclined to use a spreadsheet to perform some of her calculations. Sarah spoke of how she was doing more calculations in her head and using the GC for more complex calculations or to check her own solutions. These instances indicate that she was aware of the potential and drawbacks of the different pieces of technology and was selecting the most apposite one for the task on which she was working.

This corresponds to the definitions of appropriation as described by Wertsch (1998) and Guin and Trouche (1999). Sarah displays the beginnings of ownership and mastery by relying solely on the GC from the first day. She underwent an initial period of familiarisation with the technicalities of the tool or instrumentation and she experienced some instrumentalization of her GC as she is aware of its potential and begins to use it selectively as and when she believes it is apposite. While she has not appropriated or even mastered all of the GC there is a sense that she is moving towards appropriation and by the end of my data collection period she had progressed further towards appropriation than any of the other students in my project. Guin and Trouche (1999) write that it is this process of instrumental genesis that has the potential to influence a student's problem-solving and knowledge construction of the mathematics at the centre. They write that the technology assists conceptualisation through visualisation and the multiple representations that this type of technology can provide. Guin and Trouche state a student will progress from the discovery phase to the organisation phase and

> "...*substitute work* with *an artefact for work* on *it*." (p.224)

and that

> "*It is only through a complex process that students will be able to combine different available sources of information (theoretical text, a calculator, calculation by hand) to construct their own mathematical understanding.*" (p.199)

9.3.3 Barriers to Appropriation

There are, no doubt, countless explanations why a student would or would not appropriate a GC. Wertsch (1998) describes the existence of some level of resistance between the agent and the cultural tool, in this case the GC, as the reason why someone may not appropriate a tool. Mastery and appropriation are usually positively correlated but if there is the presence of sufficient levels of resistance it is possible to master but not appropriate the tool, and in fact if it reaches extreme levels the agents may refuse to use the tool altogether.

Through analysing all the data collected from my study it seems apparent that with the students I followed there are five areas that are prominent when considering their lack of appropriation or reluctance to appropriate the GC – old tool/new tool issues, institution, curriculum, disappointment and frustration.

9.3.3.1 Old Tool/New Tool

Many navigation issues were experienced by all the students over the year. They had problems moving between screens, navigating around the screen and also they had difficulties finding specific keys or functions. Further details of all of these can be found in sections 8.1.2.4 Difficulties (p.88) and the student case studies (p.97).

David experienced problems locating the exponential key. He was expecting it to be the $\boxed{x^y}$ key as it was on his scientific calculator but it was the $\boxed{\wedge}$ key on the TI-83+. Sarah also experienced problems locating keys on her GC – she said that she expected the GC to be similar to her old scientific calculator – an instrument which she had appropriated and was trying to transfer knowledge from that instrument to the GC. Steve encountered problems locating keys on his GC because he was familiar with his scientific calculator. This seemed to be a recurring theme. The students are familiar with their old scientific calculator and while some of them are reluctant to adopt a new tool, they are also trying to transfer their knowledge gained from their experience of using their scientific calculator to using the GC.

Problems navigating around the different screens on the GC also seem to be as a result of the students attempting to transfer their knowledge of another instrument to the GC, namely the WP. There is evidence to show that they are attempting to alter previous entries on the HOME screen by using the cursor keys to move UP, DOWN, LEFT, RIGHT as can be performed on a WP. Instances of this did seem to diminish as the year progressed and the students became more familiar with the GC but the instances of the students experiencing problems locating keys seemed to occur throughout the year. Even though they thought they were familiar with the GC they still encountered problems trying to locate the key that they required as they encountered new areas of mathematics.

There was some noticeable resistance to the GC from some of the students because they were familiar with their scientific calculator. David and Sam both thought the GC was too big. Max, Sam, Ann, and Steve all spoke of how they would use their scientific calculator alongside their GC until they were confident in using the GC. They had used the scientific calculator for at least five years and were aware of what it could do as well as how it could benefit them with their mathematics problem-solving. They were confident using it and understood, for the most part, the syntax of this piece of technology. The appropriation of the scientific calculator did not happen overnight but in fact the students had five years where they were taught to use it and gradually learnt most of the features. Within my study the students had only one year of its use and were not able to access any in-depth formal training. Graham (1992) studied two groups of students in year 12/13 using a new calculator. The first group were left to explore the calculator while the second group were given some worksheets that provided exemplars of how to take advantage of the features of the new tool. At the end of the study the first group were significantly less motivated and more critical of the new tool. They also tended to rely on the old tool when the opportunity arose. There is a big step to be taken when moving from an old and familiar tool to a new toll. Graham (ibid.) writes

> *"I suspect too many students are simply unwilling to take the first brave step onto the steeply-rising start of the learning curve."* (p.26).

There is little surprise then that the majority of students in my study experienced some difficulties in appropriating this piece of technology for their studies. They were at the start of a daunting learning curve and were given only limited training and guidance on how to use their new tool.

The students experienced problems learning not only new mathematics with a new tool but it was also necessary to learn the slightly different syntax for their tool. There were some instances where the syntax of the GC proved problematic for some of the students. On one occasion, while working on a trigonometric problem, Sarah confused the syntax of the scientific calculator she had previously used with that of the GC. She typed $0.5 \tan^{-1}$ instead of $\tan^{-1}(0.5)$. Also the continued problems with standard form were as a result of four of the students holding the same misunderstanding, that the syntax of the hand-written calculation could be transferred to the GC. Brown and Davies (2002) write about the introduction of GCs into examinations and describe the problems associated with syntax. There may be slight changes of syntax from tool to tool resulting in different outputs and Brown and Davies (ibid.) state that the syntax "*can be a trap for the unwary*" (p.179).

The transition from using from an old and familiar tool to a new tool can be a difficult process. Syntax and navigation are only two of the many pitfalls that a student may experience. Without sufficient training the students can become unenthusiastic and disillusioned with the new tool and the level of resistance to it can increase to unworkable levels.

9.3.3.2 Institution / Environment

This study adopts a socio-cultural perspective and so it is important to consider the impact of the context or environment in which these six students learn. These contexts may indicate the cause of a student's lack of appropriation. Lerman (2001) uses the analogy of "zooming in" to refer to the focus of the students and "zooming out" to consider the context in which the students learn and it is this concept of "zooming out" that I consider here.

The students who took part in my study had different GCs than those of the rest of their peers. In school A the GC available to students was a completely different make and model GC to one I provided to the students. When the students have a different tool to the rest of the class, these students may encounter some difficulties. Not only do they have a different tool but they may feel excluded from the rest of the group and also excluded from any training offered by the teacher as it does not apply to them. In school B the students used a TI-82 which had many similar features to the TI-83+. Both teachers whose students I followed did not fully integrate the GC into their teaching but used it almost as an add-on tool. They didn't seem to be taking advantages of its features and eventually the students were using it as they would use a scientific calculator. Doerr and Zangor (2000) write that as an individual uses the GC it becomes more familiar and through this familiarity they are able to use it more effectively. In reality both groups of students were left to explore and investigate the features and functions of the GC for themselves and they did not achieve very high levels of familiarity. As mentioned above, Graham (1992) writes that in situations where there is a lack of training or students are left to explore and investigate for themselves they are inclined to become unmotivated and resistant to using the GC, which is in effect the reaction of the majority of the six students in my study. They were left with a sense of disappointment (See 9.3.4 Disappointment) but this was probably not confined to the students in my study.

To zoom out even further, one influencing factor may be the level of use of the GC permitted by the examination boards. At present GCs are only permitted in some AS and A2 Level module examinations and the examinations where GCs are permitted are designed to ensure that students without a GC are not disadvantaged in any way. If considered from a different angle it can be seen that it is still possible to succeed at AS Level Mathematics without a GC, which is message that the teachers appeared to perpetuate by referring to the GC as a checking device during these examinations. Teachers face tremendous pressure to produce good examination results for their students in a short period of time and it is sometimes the case that the teachers believe there is insufficient time to teach the students to use the GC as well as all the mathematics topics (Sheryn 2002). Doerr and Zangor (2000) state that there is a strong relationship between the teaching strategies employed by a teacher and how a student uses a GC. If a teacher is making little or no reference to the GC the students are unlikely to consider it as an effective problem-solving tool but if a teacher adopts an encouraging and active use of the GC it will results in a higher level of use of the GC by students which can in turn lead to ownership, mastery, instrumentation and instrumentalization.

9.3.3.3 Curriculum

The curriculum is currently designed so that students without a GC will not be at a disadvantage when compared to those students with a GC. However this can lead to some confusion for some students – why are they being asked to learn to use a new tool when it will not change the way in which they approach mathematics problems, and it offers no advantage during examinations.

9.3.3.4 Disappointment

As described above in 9.1 Stages of Appropriation, David used his GC in a way that indicated that he was beginning to appropriate elements of his GC. However throughout the year David does seem to make comments that denote he was disappointed with the extent to which he was using his GC. He described his use of the GC in ways and in terms that implied he was dissatisfied with it, and that he was not yet using the GC in the way in which he envisaged he would. Apart from certain aspects of the GC – graph function and the statistics menu – David described his use of the GC as being like the scientific calculator.

> "*I've just been using it for everyday use, like we did for the scientific calculator... I used it for basic calculations... It's only been for minor things, it hasn't been for huge pieces*" (Int1, p1, September 2003)

> "*...I've been using it for basic calculations... haven't really used it for much challenging stuff as of yet.*" (Jrnl1, October 2003)

> "*I am finding the calculator quite easy although I haven't really used it for anything new.*" (Jrnl2, November 2003)

At the beginning of the year David seemed to have the expectation that the GC would transform the way in which he did his mathematics and it was the slow realisation that it would not that led him to experience some degree of disappointment. Sarah also talks with some dissatisfaction that they – the students – were not taught how to use many of the features of the GC, instead they were left to explore it for themselves.

> "*They* [the teachers] *would teach us all and even then only one button at a time. This button does this function. That's about it really*" (p.3 Int3, July 2004)

Guin and Trouche describe how the integration of technology into the classroom also brings about the changing role of the teacher to one of technical consultant and to "*organise and encourage interaction*" with the technology (p.199). A lack of training can lead to a misunderstanding which if left unaddressed could seriously impact on a student's future understanding of mathematics. For Sarah, her disappointment stemmed from a lack of training provided by the teachers.

All the students mention not being able to take their GC into all of their examinations for the AS Level Mathematics modules. While this was not mentioned as a barrier to appropriation by the students in school A, I believe that although they may have been eager to adopt the new tool, but by the time of the examination in January (where GCs are not permitted) they realised that they were really only using the scientific calculator functions on the GC. This made the move from using the scientific calculator back to using the GC a relatively difficult step for Sam and Ann. They were familiar and comfortable with using the scientific calculator and realised that they would be able to complete their mathematics work without the use of a GC.

9.3.3.5 Frustration

The level of frustration experienced by a student is difficult to determine through the majority of data collection techniques. However there were instances, during interviews, when some of the students implied that they were frustrated by the GC. There is also Key Recorder evidence that confirms this sense of frustration was experienced by the students. There were several instances when Steve, after experiencing some difficulties and creating an error, became so frustrated that he turned the GC off and started again. He did not understand the error message and found the easiest way was to delete the entire calculation and begin with a clear screen. David and Sarah also experienced some levels of frustration when the GC did not react in an expected way. Their frustration resulted in them pressing the CLEAR key multiple times – on one occasion Sarah pressed the CLEAR key 50 times after she created an error by trying to STORE 12 into zero.

The students in my study all experienced some problems with the GC over the year. These difficulties may have had a detrimental affect on their understanding of the mathematics involved. The feedback or lack of feedback, provided by the GC may confuse the students further. Monaghan (1997) describes this as "*cognitive noise*" and writes that

> "*Perhaps we do not get an output or cannot make sense of the output we get... We get an unwanted loop of 'cognitive noise' that can effectively obscure the mathematics at the heart of our use.*" (p. 216)

The frustration and disappointment experienced by the students which resulted from navigation issues, syntax issues or the appropriation of the scientific calculator led most of the students, to some extent, to put up some barriers to appropriating the GC. However it appeared Steve was the only student who experienced such great levels of conflict that, as Wertsch suggested, he returned to the comfort and familiarity of his scientific calculator.

Chapter 10 – Conclusion

This chapter provides a summary of my findings and outlines what factors I believe may encourage appropriation. I also review the Key Recorder software as a data collection tool. The final two sections consider the limitations of my study and areas for possible further research.

10.1 Final Discussion

In Guin and Trouche's (1999) study into using CAS within the classroom, they acted as teacher-researchers and were able to train their students in the use of the CAS as necessary. In my study I decided to take the role of non-participant observer, although on occasions I was encouraged to participate in the classroom session by both teachers and students. My aim was to have as little impact on the classroom activities as possible and so I decided not to offer any training to the students unless they directly asked me. In Guin and Trouche's study there a great focus on the technology and they organised their lessons with the CAS at the centre and students took it in turns to have their CAS linked to the projector. The sessions were designed with the intention of promoting interaction between hand-written calculation, calculators and theoretical results. It was through sessions like these that Guin and Trouche developed their ideas of instrumental genesis. The sessions I observed as part of my project are not comparable with the Guin and Trouche study. The main reason is the contrasting organisation of the classrooms. Guin and Trouche organised their classes around the technology whereas the teachers in my study only marginally integrated the GCs into their teaching. The introduction of the GC into the classrooms at both schools did not change the students' problem solving strategies. From informal discussions with the teachers throughout the year and comments they made during lessons to the pupils it was apparent that they perceived the GC as a checking mechanism and they did not significantly incorporate the GC into their lessons, instead lessons were focussed on the methods and processes of problem solving that were acceptable in an examination setting.

Moschkovich's (2004) definition of appropriation includes the concept of the novice and expert working together with the novice adopting some of the procedures of the expert and adapting them for their own intention. Moschkovich is considering mathematical practices only, whereas my study considers the appropriation of a new artefact. The main difference I perceive is that in my study the teacher was not necessarily the expert with the GC and the interaction between students and teacher was focussed mainly on the mathematical practices and not the use of the GC. There was only a small amount of work on the GC with the teacher and student working together and there was little opportunity for the student to transform the teacher's meanings and actions with the GC. Left mainly on their own to use and explore the GC, the students in my study appeared to employ this new tool for largely the functions they had previously appropriated on their scientific calculator.

It became apparent that the students were engaged in three different types of learning:

- learning mathematics;
- learning how to use a GC;
- learning mathematics and learning how to use a GC simultaneously.

Learning mathematics is a distinct path that varies depending on the individual as well as the previous level of mathematical learning and the motivation to succeed. Learning about the GC is less particular to the individual. It can come about through informal exploring by the student or a more formal training led by the teacher or peer. Learning about the GC and mathematics together is again more specific to the student. This can be dependent on all of the above but also requires the knowledge that the GC can assist with mathematical problem-solving.

From my own experience I have seen that only a few students move towards appropriating their GC. Some will perceive and value its potential and are willing and enthusiastic to use it while others will put up barriers and arrive at a state of mind where they appear to reject it as a useful instrument. I think appropriation will have taken place when a student experiences 'ownership' of the instrument and adopts it as an instrument. They may need some instruction but they are keen to use it. Appropriation will manifest itself as the student willingly and frequently using the instrument whenever they are instructed and selecting it as the apposite instrument whenever they feel it is necessary. A student who has not begun to appropriate the instrument may be reluctant to use it, may not be able to see its potential for problem solving and may possibly need a considerable amount of encouragement, help and instruction when prompted to use it.

10.2 Encouraging Appropriation

I believe there are several approaches that may encourage the appropriation of technology within the mathematics classroom. Firstly, if mathematics examinations were designed where GCs were permitted for every module this would create a perception that GCs were a useful tool and students would possibly be more inclined to view this piece of technology positively. Also if training to use the GC were readily available within classrooms and teachers encouraged an exploration of the potential of the GC as well as the disadvantages, students would be more confident using this new technology.

Teachers often cite a lack of time to train students to use a GC as a reason why they do not extensively use the CG within their lessons (Sheryn, 2002). This could be alleviated if the GC was introduced earlier in a student's mathematics education. The students' in my study learnt to use an arithmetic calculator in their primary education, a scientific calculator in their secondary education and were only introduced to GCs for their AS Level Mathematics courses, and even for this they are not essential. If GCs were introduced earlier in the education system it would enable the students to gradually explore the features and functions of the GC with help from teachers as well as offering the opportunity to explore the GC further on their own if the student was inclined.

I believe that all of these approaches would provide an encouraging environment for students to use their GC and start their journey along the path to appropriation.

10.3 Key Recorder as a Data Collection Tool

The Key Recorder software was an integral part of my study. It provided a vast quantity of rich data that would have been unavailable through other data collection methods. As the software was on a piece of portable technology – a GC – the students were able to carry it with them wherever they went and it therefore enabled me to examine exactly how students used their GC in the mathematics classroom, for homework and in other subjects' classrooms. It also provided the advantage that although the students were aware I was collecting data from their GC, they did not necessarily experience the sensation of being under close scrutiny.

The quantity of data I was able to collect was vast but the method of processing and analysing the data was incredibly laborious. Each key stroke had to be viewed in order to ascertain how the student had been using the GC and with files ranging in size from 1000 to 9000 key strokes this was extremely time-consuming. Despite this I still believe Key Recorder is a tremendously useful data collection tool that provides unique opportunities to record an exact account of how a student uses a GC.

10.4 Limitations of My Study

My study was limited by the number of students involved in the study. While six students were only just manageable for one researcher a larger number of students would provide a more full and varied account of appropriation. By the end of the year all the students in my study were at different stages of appropriation. A larger group of students in the study would enable comparisons to be made across the different stages of appropriation.

The GC provided to the students in my study provided some problems. It was a different model to the GC recommended by either school A or B. The teachers were not able to adequately support their use or provide training to use that particular GC. They were unfamiliar with it and so were only able to offer training or support to the other students in their class who had the model of GC as recommended by the school. The students in my study were left to explore the GC on their own and teach themselves to use it. The results from my study are therefore not a true representation of how students appropriate their new tool in the classrooms of the teachers from school A and B.

Several of the data collection methods I employed were unfamiliar to the students, namely the stimulated recall interviews and the hierarchical focussing interview. The students were reluctant to volunteer their own opinions and responded best to a structured interview. The students were also reluctant to provide journal entries outlining their use of the GC. While the data collection methods I employed did provide very useful data, the students were unfamiliar with some of these methods and required a significant amount of guidance from me during that phase.

I believe that a great deal more information could be gathered if the students indicated when and where they were using their GC but this would rely on the student entering an alpha code. I had to rely on the goodwill of the students for not only entering this alpha code but also for journal entries. The problem here is that the students obviously perceived me as part of the school and were at times guarded with what they did and said.

10.5 Areas for Further Research

This project could be extended to cover the two years the students are engaged in studies for A Level Mathematics. Students entering AS Level Mathematics have spent five years working with and appropriating aspects of a scientific calculator and it is extremely unlikely that a student studying for AS Level Mathematics is able to partially appropriate a GC after only a year. Following a group of students and their use of a GC over a two year period would enable a student to move closer to appropriation of a GC and provide a more comparable experience to that they encountered when they were learning to use their scientific calculator. Involving a larger group of students in this type of study would provide more data indicating the different degrees of appropriation as evidenced by the students in my study. In my study the students were all at varying stages of appropriation but with a larger number of students there would be more than one student at the same stage of appropriation and a broader analysis of the reasons behind appropriation or the barriers to appropriation could be developed.

Another aspect of this study that could be developed could be comparisons between two groups of students from different schools. In one school in-depth training and support could be present and the GC fully integrated into the lessons and in the other school the students could be left to explore their GC on their own. Not only could a greater exploration of appropriation be conducted but also which group of students fared better on formal examinations and in which areas.

Appendix – Literature Review

ICT within Senior High School Mathematics Education

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Module: Directed study

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ICT within Senior High School Mathematics Education

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A1. Introduction

There has been a great deal written about Information and Communications Technology (ICT) within mathematics education in secondary schools. The authors and researches tend all to have different interests and therefore take a different focus with their projects – the classroom environment, the teacher, the ICT, the student or a combination of these. My doctoral study examines the use of ICT by students within A Level Mathematics programmes and asks if appropriation and internalisation of a technological tool may have an impact on a student's mathematical understanding. As a background to this, I have reviewed the literature written about educational issues arising from the use of technology within the high school mathematics classroom.

There is a partition within the literature on ICT in mathematics education, resulting in two sections – professional literature and research literature. The professional literature (e.g. MicroMath) is rooted in practice and although it has a clear mathematics focus it is, by its nature, subjective and often stands separate from other work. Research literature is often focussed on the ICT tool (Laborde, 2001) or on an idea or hypothesis (Artigue, 2002) and while it is often perceived by mathematics teachers to have little relevance for the mathematics classroom, I will concentrate on this type of literature because I will be able to assess where my proposed research project fits in with what has already been researched.

In the meta-study conducted by Lagrange, Artigue, Laborde and Trouche (2001) 79 papers were reviewed, mainly French and Austrian, that were written between 1994 and 1999. Using a focus of CAS they narrowed it down to 79, from 662 articles, believing their selection was broadly representative of the body of literature. They found the articles could be broken down in to five sub-categories:

Technical descriptions of possibilities of CAS (53%)
Descriptions of innovative classroom activities (13%)
Papers starting from assumptions (18%)
Papers starting from questions about the use of CAS (31%)
Papers focussing on integration (7%)

Lagrange's meta-study is not entirely clear why the percentages total more than 100, so I assume that some papers fell into more than one category. It is quite notable that the category 'Papers focussing on integration' is only 7% - the smallest of the list. Integration of CAS into the classroom is not widely written about which implies that it is not widely researched or implemented even though there are many articles outlining the possibilities of CAS.

As I am considering all technology within mathematics education I have decided to create four main sections to my literature review:

- Researchers' Interpretations
- Portable and Non-Portable
- Software and Hardware
- Impact on Learning

The two categories 'Software and Hardware' and 'Portable and Non-Portable' are closely linked because it is possible for a piece of technology to fall into both categories. For example, a computer algebra system could take the form of either a TI-92 (portable and hardware) or Derive on a desk-top (non-portable and software).

Students' attitudes to technology and how it impacts on students' understanding is important in itself and is relevant to my study. To do justice to the work done in this area would take a substantial number of words. I have decided to omit a consideration of attitudes in this paper so that I can go into depth in my four foci.

A2. Researchers' Interpretations

The integration of technology into mathematics education has the potential to transform traditional teaching approaches and also change students' learning experiences. There has been a significant amount of research into how a student's learning experience will be transformed and different researchers have different interpretations of how it will change (Papert, 1980; Ruthven, 1996; Heid, 2002).

The introduction of technology into the mathematics classroom was initially thought to be a fairly straightforward process (Monaghan, in press), however as time has progressed researchers have seen many issues emerge and this 'straightforward' process has been identified as a very complex and involved one. Researchers investigating the use of technology in mathematics education now hold many different perspectives depending on their research focus – student, teacher, type of technology, mathematical field, to name but a few. Researchers investigating their chosen focus will adopt a research perspective – radical constructivism to socio-culturalism and all points in between. Their perspective may change or develop as time progresses and areas of research develop.

Artigue (2002) considers various French studies and describes the changing perspective of researchers. In the 1990's it was evident that many researchers took the perspective of a cautious radical constructivist but this was modified over the last few years and Artigue (ibid.) believes it is now a socio-cultural perspective that seems most appropriate. However she also states that this approach can be developed to include the anthropological perspective (in which the institution, in which mathematics is learnt, is seen as being an influence) or the ergonomic perspective (in which the instrument is an influence on the learning experience).

The role of teachers also has had to change with the advent of technology into the classroom. The Mathematics Association (1992) state that although the teacher will remain a fundamental part of mathematics teaching, there are times when the teacher can take on other roles.

> "*The use of a computer ... changes a teacher from a giver of information to the guide and mentor helping pupils come to terms with the mathematics.*" (p.18)

They write that the use of ICT encourages student discussion where they can make suggestions and predictions and the teacher can develop their mathematical abilities and guide them towards appropriate methods and approaches. Many researchers (Monaghan, in press; Mathematical Association, 1992; Guin and Trouche, 1999) agree that the role of a teacher will change with the introduction of ICT into mathematics education, but will this necessarily mean that the students' participation will change as well? Students are unlikely to adapt to the introduction of technology into their mathematics classroom overnight. It is not a straightforward situation and there are many factors that may promote or inhibit their learning with technology. The Mathematics Association (ibid) writes about the use of technology in mathematics education in simplistic terms, yet it seems unaware of the potential pitfalls (Artigue, 2002) of this changing learning environment.

Guin and Trouche (1999) take a critical stance towards the integration of technology into the classroom and focus on the complexities of a tool becoming an 'instrument' in the process of learning. They believe that the teacher's role is to organise and encourage interaction with the computer environment. They write that the teacher could act as a consultant, offering advice and help when needed, but allowing the student to construct their own mathematical meanings. Discussions between students about the different strategies they have used, results they have obtained and any inconsistencies found was thought to be a useful teaching and learning strategy.

Technology in mathematics education has a history of changing perspectives. It was initially thought it would enhance students' mathematical understanding but instead it brought up new and previously unconsidered issues. This has led to a field of research that is wide and varied and with many facets that appears to be expanding and changing as more is researched and understood.

A3. Software and Hardware

A variety of tools have been used within mathematics education since the beginning of mathematics – fingers to count, tally sticks, abacus, logarithmic tables, slide rule, to name but a few. These tools have been around for many years and over time have been incorporated into the main body of mathematics education. During the last 25-30 years technology has developed at such a pace that the area of mathematics education has had to change drastically to incorporate the new technology and the new topics made available because of it.

The tools that I will focus on here are those that are considered 'new technology' –computer technology – as detailed below. However, it is very difficult to categorise this area because of the vast amount of technology available and also because some tools could be considered both hardware and software (e.g. graphical calculator). The two main areas are generic and specific mathematics software. These can be broken down into further sub-categories:

- Generic mathematics software e.g. spreadsheets; data-bases
- Specific mathematics software
  - Graph plotters
  - Dynamic geometry systems
  - Algebra systems
  - Statistical packages
  - Programming languages
  - Integrated learning systems
  - World wide web
  - Games
  - Modelling

There has been a great deal written about the introduction of technology into mathematics education (Balacheff and Kaput, 1996; Kaput, 1992; Monaghan 1993, 1994; Lagrange et al, 2001). Monaghan (1994) provides a concise summary of the main ICT tools found in classrooms ten years ago. He considers graphical calculators, programming, computer graphic systems and computer algebra systems and summarises how it affects students' understanding of mathematics. Reviewing the International Journal of Computers for Mathematical Learning (a 'respected' academic journal) since its inception in 1996, I examined the focus of all the articles with a view to determining which technology appears most frequently. It appeared that the technologies most written about are Dynamic Geometry Systems (20%), LOGO (15%) and Computer Algebra Systems (CAS) (10%). While other types of technology have been written about the three mentioned above are most prevalent.

There is a great deal of software and hardware that could be used to enhance the teaching and learning of mathematics and yet Lagrange et al's meta-study (2001) indicates integration of technology into mathematics teaching is far from common-place.

A4. Portable and Non-portable Technology

The type of technology available to students will vary from school to school and from education authority to education authority. The technology can be loosely separated into two categories: portable and non-portable. The tools available in each category are:

- Portable technology – both generic and mathematics specific technologies
  - Generic mathematics technology – palm-top, lap-top computer with a variety of appropriate mathematics software …
  - Specific mathematics technology – scientific calculators, graphical calculators…
- Non-portable technology
  - Desk-top computers with all the appropriate mathematics software

Frequently schools will have a classroom with 15+ computers permanently setup for the students' use, however there are still some schools for which this is yet to happen. Often class-sets of graphical calculators are available for teachers and students to use although in many schools it is only the AS/A Level Mathematics students who use them. However these students are frequently asked to buy their own GC usually a specific manufacturer and model.

Hennessy (1998) provides a comprehensive assessment of portable technologies available within schools. She believes that the advantages of portable technology within education is that they are affordable, powerful, encourage spontaneous use, students have a sense of ownership and it can have a positive effect of learning and attitudes to mathematics. However, the study by Hunter, Marshall, Monaghan and Roper (1995) produced conflicting results with that of Hennessy (op. cit.). Hunter et al (op. cit.) write about a study conducted by Hunter and Monaghan where two groups of students used CAS to help them learn and understand quadratic equations. One group were given palm-tops that they could take home and the other group were given lap-tops that remained in school. The CAS was intended to improve students' learning of algebraic concepts and skills and to support investigative work. The study showed that there were some advantages and disadvantages to the students using CAS – there was evidence of improved understanding of the idea of a variable while there was a decline in the ability to substitute into an equation. However it is the pilot study that produced significantly different results. The students using desk-tops regularly created and tested their own rules – this did not occur during the main project. While the motivation of students was observed to be higher within the pilot group, the main experimental group had the advantage of taking home the palm-top. Hunter and Monaghan observed that the desk-top increased student-student discussion while the palm-top inhibited teacher-monitoring of students' activities. From this study and its pilot study it can be seen that students may not always take advantage of the technology in ways that are expected and there are other underlying factors that have a significant influence on a student rather than the portability of technology alone.

Despite all of the stated advantages of using portable technology by Hennessy (1998), in a study focussing on schools in Leeds, Rodd and Monaghan (2002) found that graphical calculators were virtually absent from all mathematics classrooms, except for A Level classes. Even in these classes the frequency of use was quite low. Although there are advantages to using technology the reasons for limited integration can be attributed to a variety of factors influencing teachers – time, confidence and support (Sheryn, 2002).

A5. Impact on Learning

Studies investigating students learning mathematics using ICT usually have a specific focus. I have identified some of these areas and review the literature that falls within. The areas are: conceptual understanding; multiple representations; visualisation; flexible approach; teachers; tasks.

A5.1 Conceptual Understanding

Many researchers (Papert, 1980; Ruthven, 1996; Hennessy, 1998; Kendal and Stacey, 2001; Heid, 2002) believe that the introduction and use of ICT within the mathematics classroom will enable students to improve their learning; however there are also many conflicting views. Many studies research the effects on learning mathematics using ICT but there is still some lack of understanding as to which students benefit and why. Gardner, Morrison, Jarman, Reilly and McNally (1992) write that

> '*... the impact of the high levels of access to IT on the learning enhancement of the experimental pupils ... was at best marginal and in the large majority of cases not significantly different from the control pupils.*' (p.4)

Generally, the studies reveal that students using technology within their mathematics education will benefit from its use. They may be able to visualise the mathematical activity and use multiple representations to increase their conceptual understanding, but also the technology will relieve them of mundane and repetitive tasks. However Hembree & Dessart (1986) extend this further with their meta-study[9]. They found that students who use calculators in conjunction with traditional methods maintain their level of understanding and in some cases – students who are average ability – their level of understanding will increase. In other words students' understanding will be not be adversely affected by the use of technology. Hoyles (2003) writes that students who use technology within their mathematics education find that their understanding is transformed.

> "*...computer tools introduce a new model of knowledge related to the functioning of the machine ... they* [the students] *have to discover whether they have conceptual 'problems' or they simply do not appreciate how the software happens to work.*" (p.3)

Heid (2002) says that technology need not just substitute paper and pen techniques but it can in fact reduce the amount of time spent on techniques in the classroom allowing for more time to be spent on developing conceptual understanding.

It was thought that technology would enable students to cut through the technical aspects of mathematics and then the conceptual understanding would follow. Artigue (2002) refers to this as the technical – conceptual cut. However, this was found not to be the case by Artigue and her colleagues. Instead it was found that technology produced its own technical issues. For example: a student is asked to simplify $1-\dfrac{1}{1-x}$. The pen and paper answer could be $\dfrac{-x}{1-x}$ but the technology may give the result $\dfrac{x}{x-1}$. Both are correct but the student needs to appreciate that technology may produce unexpected correct answers.

After the initial introduction of technology within the mathematics classroom students are faced with a difficult situation – not only are they faced with learning and understanding new mathematics they also are expected to learn how to use the new technology. The different types of technology usually require the student to learn the syntax of the technology (Heid, 2002). This means that the technology is not immediately effective as an instrument. However, it may not be the technical aspect of technology that the student takes issue with – it may be that the

[9] This is a relatively old paper and is specifically about calculators but I am unaware of a similar paper being written about other types of technology.

technology they use deprives them of a mathematical activity that they enjoy (Monaghan, 2003; Ruthven, 1996). Monaghan (2003) writes about two students who had different reasons for being reluctant users of technology. One student was a high achiever in mathematics and was reluctant to use Derive and when interviewed it was revealed that she preferred to perform the calculations by hand using paper and pen. Technology reduced her involvement with the mathematics. The other student was an able mathematician but disliked using Excel because he liked repetitive calculations and the technology deprived him of this activity.

There is a strong focus within some French studies of the importance of developing a relationship with a piece of technology (Guin & Trouche 1999, Artigue 2002). Guin and Trouche (1999) conducted a study where a group of students were given a computer algebra system (CAS) to use at home and at school. They found that over time a relationship developed between the student and the tool. The students appropriated the tool. Their project focussed on TI-92, although they state that their findings could well be adapted for all calculators. They describe this relationship as the use of the artefact in conjunction with personal or social schemes. Artigue (2002), commenting on mainly French projects during the last ten years, states that calculators do not become a valuable instrument until the student has mastered their tool and this process can take some time. It will require the student developing a relationship with their instrument on a personal and social level and understanding its potential and constraints. If this can be done the effect of the technical-conceptual cut may be transformed.

This is a major focus for my study – if the student can appropriate or internalise the GC then it becomes an instrument to help with problem solving and the student will need to consider how to use the GC but will be able to focus on the mathematics problem. Schneider's (1999) project observed this happening on several occasions throughout her project although she admits that very few 'hard facts and figures' were gathered on this.

A5.2 Multiple representations

There are a number of papers that state that the use of ICT within mathematics education is desirable because the students are able to make links between the various representations – algebraic, numeric, and graphic. Hennessy (1998) writes that

> "*...linking multiple representations provides a promising environment for developing understanding of notoriously difficult symbolic ideas and techniques.*" (p.30)

Using CAS to investigate an equation, a student would be able to display it as either a factorised or simplified equation, a numerical table showing specific points in the relationship between the variables, or as a graph which could illustrate the general pattern between the variables.

Although this seems reasonable, during my own teaching experience I have found this is not necessarily the case. The students I have taught seem reluctant to make any connection between these representations. It appears that they believe each representation should be isolated from the others and that feel more comfortable if algebra is separated from graphs which is separated from numeric values. This may be because the mathematics curriculum separates the three representations and anticipates that they are taught individually.

Heid (2002) writes that CAS allows students to compare the different representations of mathematics and discover the relationships between them. It also affords the students the opportunity to identify potential pitfalls of the different representations. Technology will impact on how the students are able to convert from one representation to another and also if they are able to interpret what they learnt in one representation and transfer it to another. She believes that few students are able to make connections between the different representations but need some encouragement to reflect on the relationships between them.

A5.3 Visualisation

Several authors cite visualisation as one of the major benefits of ICT within mathematics education (Arcavi and Hadas, 2000; Balacheff and Kaput, 1996; Hennessy, 1998). These authors claim ICT enables students to see the relationship between a graph or a geometric shape and its transformation. It will enable students to begin to make conjectures and identify or visualise the problem before moving into the algebraic activity. Arcavi and Hadas (2000) write that the algebra may then come alive and add insight into the analysis. Technology is thought to benefit the students as they are able to experiment and explore mathematical concepts. This in itself can lead to misconceptions as students can misinterpret what they see on the screen. Guin & Trouche (1999) quote Goldenberg

> "... *students often misinterpreted what they saw in graphic representations of functions. Left alone to experiment, they could induce rules that were wrong...*"
> (p.196)

An example offered by Guin and Trouche (ibid.) is that students might assume that asymptotes are part of a graph since they appear on a graphical calculator display when entering certain graphs e.g. $y = \tan x$. The calculator can be very influential to mathematically weaker students. They may be inclined to believe entirely what it says or displays, including their own misconceptions.

A5.4 Flexible approach

The introduction of technology into mathematics education may mean a new approach to the curriculum and that traditional teaching schemes may need to be adapted (Arcavi and Hadas, 2000). Arcavi and Hadas (ibid) state there are many different approaches and any one method may not be appropriate for every student and ask if it worth putting forward several approaches and let the students choose the one that is most appealing to them.

There are many different approaches to classroom organisation when using technology to teach and learn mathematics. Guin & Trouche (1999) organised a class of students using TI-92s where one student's CAS was linked to a projector. The students took turn operating the projected CAS. This student-led approach encouraged classroom debate and allowed the teacher to assess the strategies used by the students to solve problems. It also encouraged students to discuss each other's strategies and the teacher was able to direct discussions about how to achieve mathematical consistency among the pairs of students.

Schneider (1999) describes how the introduction of CAS technology into two classrooms, at two different schools resulted in different classroom organisation. The teachers within her project, in conjunction with the researchers, developed a workbook for students to follow during the mathematics lessons. The introduction of CAS resulted in the amount of teacher-led work being reduced from 88% down to 53% and also the amount of group work rose from 0% to 17.5%. It was also revealed that students became more active within the classrooms – dominating the conversation to a greater degree – and more than three-quarters of the students were actively participating within lessons.

There are many potential different approaches to integrating ICT into mathematics lessons and whichever approach is adopted, we as researchers should bear in mind that technology is at its most useful when it is used appropriately (Arcavi and Hadas, 2000; Hennessy, 1998; Ruthven, 1990, 1996). Arcavi and Hadas (2000) say that technology can nurture a student's understanding and mathematical cognition if it accompanied by suitable materials and classroom practices.

A5.5 Teacher

It is widely thought that using ICT will have an impact on students' understanding (Artigue, 2002; Guin & Trouche, 1999; Hennessy, 1998; Heid, 2002) however Monaghan (1993) writes that ICT in general may not have an immediate effect on students' understanding of mathematics if at all, but it does have a dramatic effect on the teaching of mathematics. The curriculum may need to be adjusted to incorporate the technology or to place restrictions on technology during testing. Teachers also need to make decisions about when it is appropriate to sue technology and when it is more appropriate to use pen and paper techniques.

However in 2004 there seems to be a significant gap between the availability of technology in mathematics classrooms and its integration into teaching schemes. Rodd and Monaghan (2002) write about the low level of use of graphical calculators in A Level Mathematics classes within Leeds. Teachers are not necessarily changing their style of teaching to integrate ICT, instead they seem to be using ICT as an addition to their usual style of teaching and some are just using it as a checking device. To corroborate this, during the data collection phase of my doctoral study the two teachers, whose students I am following, have both referred to the graphical calculator as 'a checker' because it is not permissible in all of the AS mathematics examinations.

Various researchers (Guin and Trouche, 1999; Mathematical Association, 1992; Heid, 2002) believe that as technology is integrated into the curriculum, the teacher's role changes to that of catalyst, facilitator or technical assistant and that a teacher should encourage students' interaction with technology. Monaghan (in press) disputes this, and writes that although this was the initial stance of researchers during the 1990's teachers should now be thought of as 'mediators'. Monaghan (ibid.) bases this on his experiences that teachers find it difficult to become facilitators and when integrating technology into their lessons they usually resort to their 'normal' teaching practices.

A teacher has many choices regarding how to incorporate technology into their mathematics lessons: the subjects to teach with it; the technology itself; the level of integration. The way a teacher teaches and what they decide to teach will have an affect on the students and how they learn and what they learn. Kendal and Stacey (2001) describe this as 'privileging'. They followed two teachers teaching differentiation who both followed the same teaching scheme but made their own pedagogical choices as to how they interpreted the topic and how they taught it using CAS. The two groups of students were achieving in different areas: the students of the teacher privileging conceptual understanding were better able to interpret derivatives; the students of the teachers privileging the performance of routines were better able to solve routine problems. Other authors have come to the same conclusions (Arcavi and Hadas, 2000; Noss and Hoyles, 1996).

The institution in which teaching and learning take place can also have a significant impact on students' understanding. Mathematics will be affected by the social and cultural environment as it is the product of human activity (Artigue, 2002; Verillon and Rabardel, 1995). Any social or cultural activity will take place in an institution (a school, family, classroom…) and each institution has its own practices and will lead to differences in knowing or understanding. Artigue writes about Chevallard's anthropological approach to research where he states that it is important to analyse the practices of the institution to realise the meaning of knowing and understanding within that institution. Laborde (2001) conducted a study of teachers and students using Cabri. She found that if mathematics is taught within a Cabri environment then new knowledge is institutionalised within the Cabri environment. Although the tasks developed by the teachers covered the content as prescribed in the curriculum they included activities that were especially designed for using Cabri. The students were unable to transfer their knowledge from the Cabri environment into the pen and paper environment. Eventually the experienced teachers gave assessments using Cabri and this legitimised the use of Cabri.

There is a great deal of government incentive to integrate technology within the mathematics classroom. There is funding and training available to schools from different sources – New Opportunities Fund[10], National Grid for Learning and British Educational Communications and Technology Agency[11]. However despite these initiatives and incentives there is little evidence

[10] The New Opportunities fund (www.nof.org.uk) provides ICT training to enhance teaching across all subjects by improving, and thereby, increasing, the use of ICT in the classroom.
[11] For further information see National Grid for Learning (www.ngfl.gov.uk and British Educational Communications and Technology Agency (www.becta.org.uk)

that this is actually happening (Guin and Trouche, 1999; Rodd and Monaghan, 2002; Sheryn, 2002). Some of the reasons teachers are using technology infrequently is because there are limited resources available; they feel the amount of time needed to dedicate to teaching with technology is too high; they lack in confidence to teach with a new tool (Sheryn ibid.).

Laborde's (2001) study of teachers using Cabri found that using pen and paper in conjunction with Cabri can prove confusing to students and lead them to rely on the more familiar paper and pen techniques. The tasks designed by the teachers did evolve over time but initially the teachers with limited experience of technology used Cabri mainly as a tool to aid visualisation, while the teachers with ICT experience used it as a teaching aid and as a tool for problem-solving. Laborde found that Cabri was used in different ways: it was used to introduce a new topic; to identify the properties of Cabri that were needed for a specific task; Cabri was used to reinforce properties and mathematical concepts and then teacher consolidated the ideas in a traditional school format.

Any type of technology may be interpreted in different ways by different teachers and as a result students may construct their own interpretation of it as well. Lins (2001) studied teachers using Cabri-Géomètre and Excel and how they incorporated it into their lessons. She found that teachers may create their own meaning from Cabri and this may not be the same as was originally intended. If this is the case it is important that when considering approaches to using Cabri (or any other technology) to be specific about what 'type' of Cabri are being constituted by them in order to teach and learn mathematics successfully in an ICT environment.

A5.6 Tasks

When using ICT to teach and learn mathematics it is essential to reconsider the mathematics involved and the tasks been given to the students. Consideration should be given to ensure the technology in question is appropriate for the specific topic and also appropriate for the students. If not it is possible that the technology may either trivialise the mathematics or, at the other extreme, develop the students' mathematical thinking. An example of how the introduction of technology may trivialise the mathematics: a student is asked to draw a cubic graph. The use of technology will require very little mathematics and just require the students to have a small understanding of the technology itself. However if the cubic is drawn by hand the mathematics involved is more wide-ranging involving calculations and understanding of where the graph will be located on the axes. Conversely, an example of how technology may develop the mathematics being studied: a student is asked to reflect three quadratic graphs in the x-axis. By hand this task is an artistic challenge whereas by using technology it involves significant mathematical thinking.

Laborde (2001) indicates the importance of task design. In her study of teachers using Cabri, Laborde (ibid.) identified four main roles assigned to Cabri:

- Tasks in which Cabri facilitates the material aspects of the task

- Cabri as facilitating the mathematical task
- Tasks modified when given in Cabri
- Tasks only existing in Cabri

Initially the tasks devised by the teachers still involved a great deal of pen and paper work and Cabri was limited to confirming pre-existing facts. But over time the teachers did modify the tasks and they evolved into tasks with greater autonomy for the students. The style of task is crucial as it may result in mathematics being transformed. Care should be taken to endure that the focus is on the mathematics and not solely on how to operate the technology (Schneider, 1999).

A6. Issues Arising that may have an Impact on my Study

For my study I am taking an approach similar to that described by Artigue (2002) - a socio-cultural perspective that is informed by the anthropological approach and the ergonomical approach. I believe not only is the institution an important part of the learning environment but that the technology is also a crucial factor in shaping the learning experience.

There are many different types of technology available for use in mathematics education and a significant part of the research states the portability of the technology is a major benefit. Students can have a sense of ownership of the technology and it can be perceived as personal. Prolonged and regular access to it is also viewed as a major benefit. The volunteer students in my study are using a GC and obviously these advantages apply to the use of this technology. I hope that despite the conclusions of the pilot study of Hunter et al (1993) the portability of the graphical calculator will have a positive impact, although one student has already claimed that he does not use the GC very often as it is too big and does not fit into his bag!

The two different schools have a different outlook to technology. One of the schools says it is supportive of students using GCs and provides in-class instruction on how to use this technology. The other school says it provides limited support for the students and their use of a GC. The first school could be said to be 'privileging' the GC as described by Kendal and Stacey (2001). But are the differences easy to distinguish and from there is it possible to anticipate the impact on the students from that institution? The comparisons are made all the more difficult as the schools are in reality closer in their approach than initially thought.

According to the research outlined in the previous sections, the GC should improve the conceptual understanding of mathematics students but 'who benefits?' and 'why?' are important questions to address. There is a high-achieving student within my study who may, according to Monaghan (2003), reject the technology ion favour of manual calculations. However at the present time she is the one student who is appropriating the GC before the others.

The role of the teacher is said to be changing with the integration of technology but as in Lagrange et al's meta-study (2001) complete integration of the GC within my two volunteer schools has not yet happened. Any evidence of a changing approach to mathematics with the introduction of technology may be ascribed to my presence in the classroom. Will my presence affect the activities of the teachers or students?

The AS and A Level examinations allow only restricted use of GCs and the students can only use them for two out of the three modules examined at AS Level Mathematics. The students may perceive the GC as a tool that is not useful on a universal basis. As a result of this restriction the teachers seem to use the GC as a checker and to support pen and paper techniques. The teachers seem to encourage their students not to rely too heavily on it which will no doubt have an impact on the students. I believe that the teachers themselves are not wholly convinced of the usefulness and potential of the GC. Their views and opinions may be to some extent transferred to their students. I have yet to determine if my volunteer students adhere to the opinions expressed by their teachers. Are the students able to perceive the GC as an instrument that has the potential to be useful for all tasks even if, on occasion, it is more appropriate to use a different technique?

The data I collect from my study should show how the students' use of the GC develops as the year progresses. I hope to be able to analyse the burgeoning relationship between the student and their GC by examining what instructions they are given by the teacher and how they actually use the technology. Towards the end of my study I would expect to find the students making decisions about when it is appropriate to use the GC and when they should rely on pen and paper techniques.

Appropriation and internalisation of technology may be difficult to measure but I hope that taking the above into consideration I will be able to determine if GCs are a benefit to my volunteer students.

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