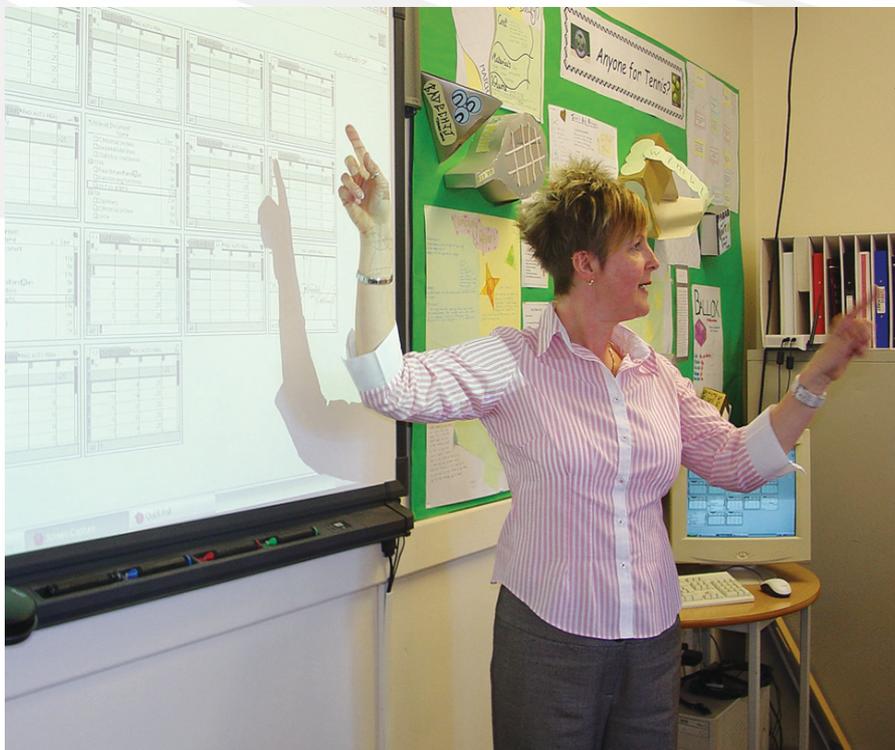


Connecting mathematics in the connected classroom: TI-Nspire™ Navigator™

Alison Clark-Wilson
The Mathematics Centre



Research Report



Published by University of Chichester, UK

College Lane

Chichester

West Sussex P021 1HR

This document is also available in pdf format from the University of Chichester website, www.chiuni.ac.uk

ISBN 978-0-948765-02-5

© University of Chichester 2009

Project Researcher

Alison Clark-Wilson, University of Chichester, UK

TI-Nspire™ Navigator™ Pilot Project Teachers

Nevil Hopley, George Watson's College, Edinburgh, UK

Cindy Hunt, Davison Church of England Girls School, Worthing, UK

Petra Ryrstedt, Allvar Gullstrandgymnasiet, Landskrona, Sweden

Jay Timotheus, Blue Coat Church of England School, Walsall, UK

Maria Waern, Åva Gymnasium, Täby, Sweden

Bert Wikkerink, Christelijke Scholengemeenschap Liudger, Drachten, Netherlands

Epi van Winsen, Scholengemeenschap Solphianum, Gulpen, Netherlands

This pilot research project was fully funded by Texas Instruments.

Contents

1	Introduction.....	5
1.1	Background to the project.....	5
1.2	The research questions	5
1.3	Why this study is important	6
2	The research context	7
2.1	Introduction	7
2.2	A brief description of the TI-Nspire™-Navigator™ system	7
2.2.1	The classroom setup.....	7
2.2.2	Overview of TI-Nspire™ Navigator™ software	7
2.2.3	Sending files	8
2.2.4	Screen Capture.....	8
2.2.5	Live Presenter	9
2.2.6	Quick Poll	9
2.2.7	Class Analysis	10
2.2.8	File collection and redistribution	11
3	Research methods: A Grounded theory approach.....	12
3.1	Overview.....	12
3.2	Selection of schools and teachers.....	12
3.3	Organising the students' access to TI-Nspire™ Navigator™	12
3.4	The methods of data collection	13
3.4.1	Teachers' evaluations of TI-Nspire™ Navigator™ lessons.....	13
3.4.2	TI-Nspire™ Navigator™ lesson components.....	13
3.4.3	Lesson observations	14
3.4.4	Feedback from students.....	14
3.4.5	Teachers' logs.....	14
3.4.6	Teachers' questionnaires.....	14

3.4.7	Data coding scheme	15
3.5	The data analysis process	15
3.5.1	Stage 1: Frequency of use of the various TI-Nspire™ Navigator™ features.....	15
3.5.2	Stage 2: Nature of the use of the various TI-Nspire™ Navigator™ features.....	15
3.6	The role of the researcher	15
3.7	The approach to the professional development	16
3.8	Ethical considerations	16
4	Findings	17
4.1	Introduction	17
4.2	Teachers' perceptions of the TI-Nspire™ Navigator™ system	17
4.3	Frequency of reported use of TI-Nspire™ Navigator™ features	18
4.4	Use of Screen Capture.....	18
4.4.1	Introduction	18
4.4.2	Monitoring student activity during lessons.....	19
4.4.3	Supporting teacher interventions	19
4.4.4	Promoting whole class discourse.....	20
4.4.5	Promoting and supporting peer assessment.....	20
4.4.6	Privileging mathematical generalisation	21
4.4.7	Increasing sample sizes (within statistical work)	21
4.4.8	Enabling mathematical sorting	22
4.5	Use of Live Presenter	22
4.5.1	Supporting the development of students' TI-Nspire™ skills.....	22
4.5.2	Supporting the introduction and development of the mathematical tasks	23
4.5.3	Student use of Live Presenter to share mathematical observations, outcomes and insights	23
4.6	Use of Quick Poll	24
4.6.1	Initiating the start of lesson activities	24
4.6.2	Generating data for use during the lesson.....	24
4.6.3	Prompting class discussion	25

4.6.4	Checking student understanding	26
4.7	Use of Class Analysis	26
4.8	Use of File collection and redistribution	26
4.9	Summary.....	27
5	Discussion: What are the emerging features of teachers' uses of TI-Nspire™ Navigator™?	28
5.1	Introduction	28
5.2	TI-Nspire™ Navigator™ supporting the formative assessment of mathematics	28
5.2.1	Supporting thoughtful teacher interventions.....	29
5.2.2	Promoting purposeful classroom discourse	29
5.2.3	Supporting peer and self assessment strategies	30
5.3	TI-Nspire™ Navigator™ supporting the development of innovative tasks and approaches for mathematics	30
5.3.1	Focusing students' attentions on making mathematical generalisations.....	30
5.3.2	Creating a 'shared learning space'	31
5.3.3	Generating data for use during the lesson.....	31
5.3.4	Increasing the visible sample size within statistical work	31
5.4	TI-Nspire™ Navigator™ supporting the use of the TI-Nspire™ handhelds.....	32
5.5	TI-Nspire™ Navigator™ supporting the planning and organisation of lessons.....	32
5.6	Emerging issues relating to the classroom use of TI-Nspire™ Navigator™	33
5.6.1	Use of File collection, Class Analysis, and File redistribution	33
5.6.2	Managing the change in the classroom ethos.....	34
5.6.3	Feedback from other teachers in the pilot schools	34
5.7	Implications for the role of the teacher.....	35
5.8	Summary.....	36
6	How do these findings compare with the existing research evidence for TI-Navigator™ with TI-84s and TI-Nspire™?.....	37
6.1	Studies focusing on the use of TI-Navigator™ with TI-84 graphing calculators	37
6.2	Studies focusing on the use of the TI-Nspire™ handheld.....	38

7	Recommendations	40
7.1	Professional development with TI-Nspire™ Navigator™	40
7.2	For the development of exemplar TI-Nspire™ Navigator™ lessons.....	41
7.3	For TI-Nspire™ Navigator™ product development.....	41
7.4	For further research	42
7.5	Limitations of the study.....	42
8	Table of figures	43
9	Table of Tables.....	44
10	Glossary.....	45
11	Appendices	46
11.1	The pilot schools	46
11.2	Timeline of key project activities	47
11.3	Pilot schools' allocations of TI-Nspire™ Navigator™ resources.	48
11.4	TI-Nspire™ Navigator™ Lesson evaluation proforma	49
11.5	Data coding schema	51
11.6	Teachers' early perceptions of TI-Nspire™ Navigator™	52
11.7	Outline of reported TI-Nspire™ Navigator™ lessons and the supporting data	54
11.8	Analysis of TI-Nspire™ Navigator™ lessons by feature used	57
11.9	Summary of students' written feedback [BJT2]	59
12	References.....	60

1 Introduction

1.1 Background to the project

In 2007-8 Texas Instruments commissioned the University of Chichester to direct the TI-Nspire™ pilot evaluation research project in seven English secondary schools. The outcomes of this research were published in November 2008 (Clark-Wilson 2008). Two of the original English pilot schools were invited to be evaluation sites for TI-Nspire™ Navigator™ along with a school in Scotland, two schools in the Netherlands and two schools in Sweden. The resource being evaluated in this study offers a handheld ICT based environment which includes a full suite of mathematics software packages that enables mathematics to be experienced through its multiple representations (TI-Nspire™, Texas Instruments 2007a), with the addition of a classroom wireless network system (TI-Nspire™ Navigator™, Texas Instruments 2009).

The methodology adopted by the research encouraged the participating teachers to develop a systematic approach to evaluating their own classrooms by providing a common lesson evaluation proforma and the necessary support for them to complete this with confidence.

The project began in May 2009 before TI-Nspire™ Navigator™ was available for purchase in Europe. For the period of the pilot the teachers were using TI-Nspire™ Navigator™ software version 1-0-3065 with TI-Nspire™ handhelds version 1.6.

1.2 The research questions

The research sought to collate evidence about the aspects of the classroom use of TI-Nspire™ Navigator™ that promoted desirable classroom pedagogies and the nature of the rich mathematical starting points that led to enhanced student engagement and achievement in mathematics. This evidence was analysed to consider implications for the changing role of the teacher and how the classroom system is transformed. The pilot sought to evidence if, when, why and how the interactive classroom works, albeit from a limited evidence base. The focus of the pilot was limited to the following TI-Nspire™ Navigator™ functionalities: File management, Screen Capture; Quick Poll; Live Presenter; Class Analysis.

A set of subsidiary evaluation questions were focused on each of the TI-Nspire™ Navigator™ functionalities as follows:

Screen Capture

- What was the nature of the 'rich' mathematical starting points for which Screen Capture stimulated pupils (and teachers) to learn mathematics?
- How could Screen Capture be used to maximise the opportunities for students' peer communication with (and independent of) the teacher;
- What classroom strategies did the teachers devise to use data from Screen Capture to support them in all aspects of formative assessment?

Quick Poll

- What sort of Quick Poll questions promoted formative teacher and peer assessment of mathematics during the lesson?
- How was Quick Poll used to collect data for immediate mathematical use by pupils during the lesson activity?

Live Presenter

- How did teachers choose to use Live Presenter during lessons in both a planned and impromptu way?

Class Analysis

- How did teachers make use of Class Analysis during lessons in both a planned and impromptu way?

1.3 Why this study is important

A number of studies have focused on the use of the TI-Navigator™ system for the TI-84 graphing calculator (Dougherty 2005; Hivon et al. 2008; Penuel 2008; Sinclair 2008). However, since TI-Nspire™ Navigator™ is a new product, there are no published studies focused on the classroom use of TI TI-Nspire™ Navigator™ by teachers. Consequently this study will offer an initial framework for the emergent practices of secondary mathematics teachers in this new environment.

2 The research context

2.1 Introduction

To set the context for this research evaluation, what follows is a brief description of the functionality of the TI-Nspire™ Navigator™ classroom system, which was being used with TI-Nspire™ handhelds. A fuller description of the functionality of the TI-Nspire™ handhelds can be found in Clark-Wilson (2008) and the TI-Nspire™ product manual (Texas Instruments 2007b).

2.2 A brief description of the TI-Nspire™-Navigator™ system

2.2.1 The classroom setup

In all of the pilot classrooms the teachers were using TI-Nspire™ handhelds with TI-Nspire™ Navigator™ wireless cradles in normal classrooms with the teachers' computer connected to a data projector. Some classrooms were also resourced with an interactive whiteboard. Teachers had installed the TI Network Manager software and set up the classroom network through the Access Point to the teacher's computer.



Figure 2.1 The TI-Nspire™ Navigator™ classroom setup

2.2.2 Overview of TI-Nspire™ Navigator™ software

The TI-Nspire™ Navigator™ software provided the organisational platform for the lessons. Student names had been entered (or imported) in advance of the lessons¹ to create the 'Class'. This facilitated the distribution and collection of TI-Nspire™ files from the teacher's computer to the handhelds and provided the organisational starting point for Screen Capture, Quick Poll, Live Presenter and Class Analysis. It was also possible for teachers to use the TI-Nspire™ software by connecting their own

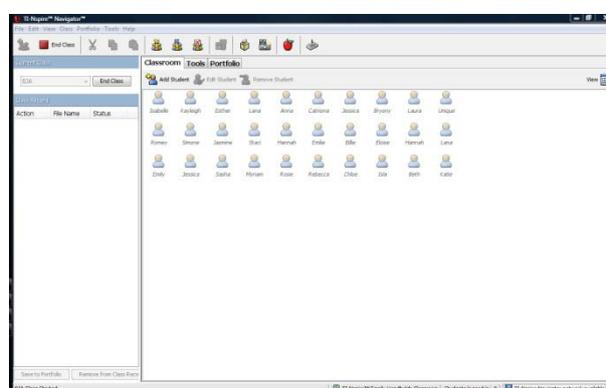


Figure 2.2 TI-Nspire™ Navigator™ software

¹ In some cases these imported class lists of named students, in other classrooms a generic class had been set up (s11, s12 etc.).

handheld and delegating themselves as the teacher. (The alternative approach would be to 'leave' the TI-Nspire™ Navigator™ software and use the TI-Nspire Teacher Edition™ software).

2.2.3 Sending files

Once the class had been started and the students had logged into the system from their handhelds, it was possible for the teacher to send a TI-Nspire™ file to the students' handhelds by navigating to its location on the teacher's computer. A variety of send options enabled them to select the whole class or individual students, as required.

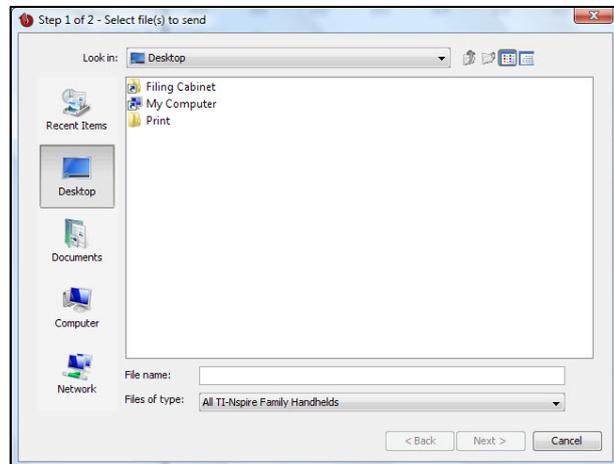


Figure 2.3 Sending files

2.2.4 Screen Capture

Once the class had been started and the students had logged into the system from their handhelds, it was possible for the teacher to show all of the students' current handheld screens using Screen Capture. A variety of display formats are possible and the screens can be repositioned by dragging and dropping. The screen is automatically refreshed according to preset time values and the screens themselves can be saved.

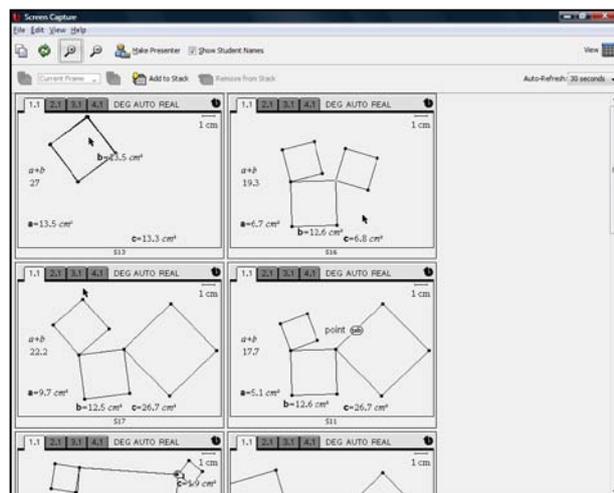


Figure 2.4 Screen Capture [From lesson BJT2]

2.2.5 Live Presenter

From the Screen Capture view previously described it is possible to select one of the handheld screens and make the owner of it the Live Presenter. Their screen action is then broadcast to the whole class. It is possible to show the key press history and record the screen action as a video file.

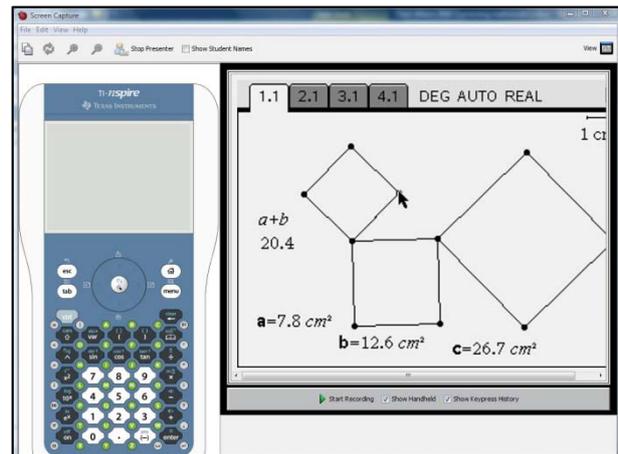


Figure 2.5 Live Presenter [BJT2]

2.2.6 Quick Poll

The Quick Poll facility enables the teacher to send an immediate poll to the students which interrupts their activity on their handheld with a pop-up question. The questions can be structured to be Open response, Agree/Disagree, Yes/No, Right/Wrong, True/False, Always/Sometimes/Never and Multiple Choice.

The poll can be started, paused and stopped by the teacher and, once stopped the results displayed with and without the students' names. A number of analysis features enable the results to be explored by common answers, a graphical display and individual students' answers.

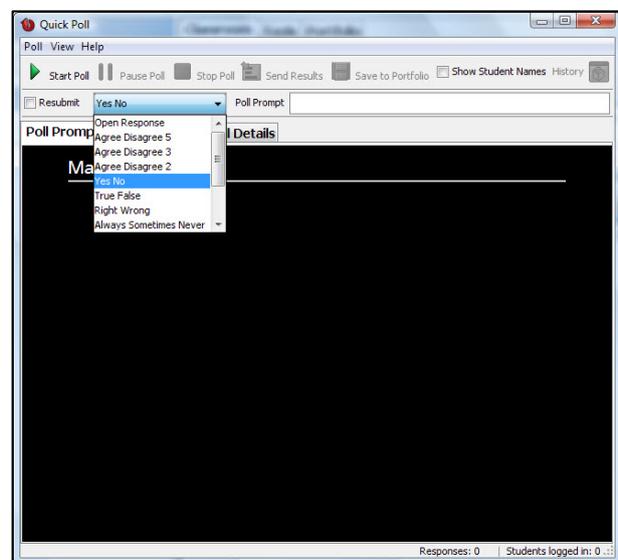


Figure 2.6 Quick Poll

2.2.7 Class Analysis

This is a more sophisticated assessment tool which integrates functionality from TI-Nspire Teacher Edition™ where it is possible to create embedded questions in TI-Nspire™ student files.

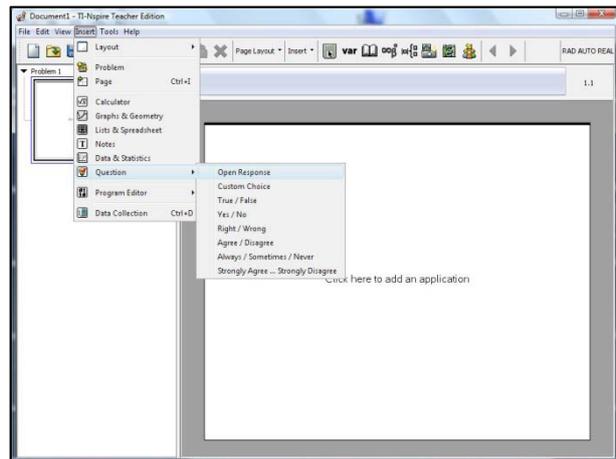


Figure 2.7 TI-Nspire Teacher Edition™ software: Question creation for use in Class Analysis

When the file is sent to the students, they answer it at their own pace and, on saving their TI-Nspire™ file on the handheld, their responses are saved.

The teacher then collects the students' files using the TI-Nspire™ Navigator™ software and, on doing so, adds them to the Class Portfolio.

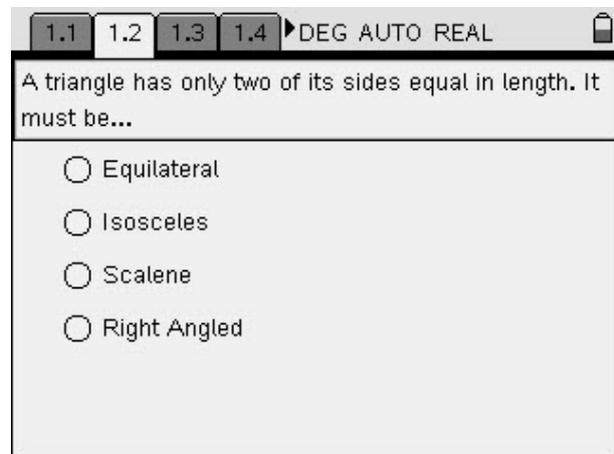


Figure 2.8 Example of TI-Nspire™ question [GNH1]

This then facilitates the detailed analysis of the individual and group responses. Depending on the nature of the question type (Open response, Yes/No etc.) and whether the teachers had identified a 'correct' answer, the results are displayed in different formats.

The screenshot shows the 'Class Analysis' view in TI-Nspire software. It displays a summary of student responses for a specific item. The table below represents the data shown in the screenshot.

Students	1	2	3	4	5	6	7	8	9	10	Score	% Sc.	Exclu.
Maximum Score	1	1	1	1	1	1	1	1	1	1	10	100%	
Amir, Amir	1	1	1	1	1	1	0	0	1	1	8	80%	
Amir, Amir	1	1	1	1	1	0	0	0	1	1	6	60%	
Amir, Amir	1	0	1	1	1	1	1	1	0	1	8	80%	
Amir, Amir	1	0	1	0	1	0	1	1	1	0	6	60%	
Amir, Amir	1	1	1	1	1	1	1	1	1	1	10	100%	
Amir, Amir	1	1	0	0	1	1	0	0	0	1	5	50%	
Amir, Amir	1	0	1	1	1	0	1	1	0	1	7	70%	
Amir, Amir	1	1	1	1	1	1	0	0	0	1	7	70%	
Amir, Amir	1	0	1	1	0	1	1	0	0	0	4	40%	
Amir, Amir	1	0	1	1	0	1	0	0	1	1	6	60%	
Amir, Amir	1	1	0	0	1	1	1	1	0	1	7	70%	
Amir, Amir	1	1	1	0	1	1	1	1	0	0	7	70%	
Amir, Amir	1	1	1	1	1	1	0	0	0	0	6	60%	
Amir, Amir	1	1	1	0	1	1	0	0	0	1	6	60%	
Amir, Amir	1	1	1	1	1	1	0	0	1	1	8	80%	
Amir, Amir	1	0	1	1	1	1	0	1	0	1	7	70%	
Amir, Amir	1	1	0	1	1	1	1	1	0	1	7	70%	
Item Average	100%	62%	86%	67%	81%	90%	43%	38%	38%	81%	6.96	69%	
Exclude Item													

Figure 2.9 Class Analysis view [GNH1]

3 Research methods: A Grounded theory approach

3.1 Overview

The research adopted a grounded theory methodology (Glaser & Strauss 1967) for the following reasons. As the main source of data for the project was the teachers' own words and descriptions of their uses of the TI-Nspire™ Navigator™ system, it was obvious that in order to make sense of this, an analysis of their texts would be necessary. As a new piece of technology, the research base for TI-Nspire™ Navigator™ is underdeveloped. Consequently a grounded theory approach would enable the categories of use and rationales to support these categories to emerge from the data and support the development of new theories about the teachers' classroom practices.

In keeping with a grounded theory approach, I avoided reading the existing research on TI-Navigator™ with TI-84s and other 1:1 networked classroom environments until after the initial data analysis phase to enable me to approach the data with a clear head. Hence this report is structured such that the review of research appears after the data analysis and serves to enable the comparison and contrast of these research findings with existing studies.

3.2 Selection of schools and teachers

This TI-Nspire™ Navigator™ pilot followed on directly from the TI-Nspire™ pilot carried out in seven English secondary schools during 2007-8 and reported in Clark-Wilson (2008). Two of the teachers (from England) and one of the project mentors (from Scotland) were invited to trial the TI-Nspire™ Navigator™ system in their classrooms.

Two teachers from Sweden and two teachers from the Netherlands were also invited to take part in the pilot study. In all cases these teachers were already using TI-Nspire™ handhelds and software with their chosen pilot class of students. These teachers were chosen partly because they had a good command of the English language and would be able to actively engage with the project team. In some cases the mathematics lessons were taught in English language.

The background information about all of the pilot schools is provided in Appendix 11.1.

3.3 Organising the students' access to TI-Nspire™ Navigator™

Each of the seven pilot teachers made their own decisions about the way in which their students would access TI-Nspire™ Navigator™. In the Swedish and Dutch schools all of the students had access to their own TI-Nspire™ handheld, or had been loaned one by the school. Some of these students had been part of previous TI-Nspire™ evaluations that had begun in July 2007, whereas others had purchased their own TI-Nspire™ in

September 2008. In the English schools, the students were loaned a TI-Nspire™ handheld for each lesson and in the Scottish school two classes were involved in the pilot. In one class the students were loaned their own TI-Nspire™ handheld and in the other they were provided on a lesson-by lesson basis.

3.4 The methods of data collection

The project data comprised a range of sources, each of which is described in more detail below. The teachers were encouraged to be systematic about any data they collected, particularly when compiling the lesson components and associated students' outcomes. Each teacher was asked to provide the evaluation data for at least two teaching scenarios in which they had used TI-Nspire™ Navigator™. A brief outline of each lesson complete with a summary of the supporting data is provided in Appendix 11.7.

3.4.1 Teachers' evaluations of TI-Nspire™ Navigator™ lessons

The project adapted the lesson evaluation proforma developed for the TI-Nspire™ evaluation project (Clark-Wilson 2008). The questions were expanded to enable teachers to comment specifically on their use of Screen Capture and Quick Poll. The evaluation form did not specifically ask about the use of Class Analysis and Live Presenter as it was not anticipated that many of the teachers would be focusing initially on using this functionality. However, if they did, this was reported by the teachers within the narrative. The main emphasis of the evaluation form was to provide a framework for the teachers to tell the story of the lesson, particularly in relation to the planned and ad hoc use of TI-Nspire™ Navigator™. The lesson evaluation proforma is provided in Appendix 11.4.

The lesson evaluation questions were designed to encourage the teachers to reflect on these actions and outcomes with a view to suggesting how they might adapt or change the lessons for future use. The teachers' responses provided rich data not only with respect to the teachers' perceptions of their students' learning, but also the teachers' own learning as they evaluated their own practices.

3.4.2 TI-Nspire™ Navigator™ lesson components.

Individual teachers supplemented their lesson evaluations with a compilation of the artefacts that constituted the lesson, which will be referred to as the lesson components. Each of the teachers provided varying lesson components which included all or some of the following:

- lesson plans, which tended to be hand-written aide-memoires of the key elements of the lesson;
- a lesson structure intended for whole-class display, often using software such as PowerPoint or Smart Notebook, which seemed to replace the traditional lesson plan;
- a pre-constructed TI-Nspire™ file;
- student task sheet(s);
- other practical mathematical resources.

The teachers collated these components and submitted them to the researcher throughout the project. In most cases the information was comprehensive enough to enable the lesson activity to be understood. Where this was not the case, follow-up conversations via telephone and e-mail took place to clarify any details.

3.4.3 Lesson observations

Each of the teachers was observed using TI-Nspire™ Navigator™ once during the study. The researcher completed a lesson observation proforma which allowed the flow of activity with respect to this use to be recorded. The observations focused on the nature of the TI-Nspire™ Navigator™ use, particularly concerning the role of the teacher and the classroom learning environment. Although four of the lessons were not taught in English, it was still possible to follow the mathematics of the lesson and observe the nature of the interactions between the students' individual work using the TI-Nspire™ handhelds and the teacher's integration of TI-Nspire™ Navigator™. In the lessons taught in English, the researcher was able to identify key aspects of the classroom discourse which exemplified notable features of the teacher's use of TI-Nspire™ Navigator™.

3.4.4 Feedback from students

The project did not aim to analyse systematically the students' perceptions of the TI-Nspire™ Navigator™ system. However a number of methods were employed to capture informal student feedback as a means of providing some triangulation of the teachers' views. The project lesson evaluation proforma included a section which invited the teachers to comment on the students' evaluations of the lessons. Schools were at liberty to adopt this format into a manageable process for their own context. Several teachers asked their students to respond to evaluation questions during the final part of the lesson, either in writing or within a Notes page within their TI-Nspire™ file.

In addition, during the classroom visits students were informally asked about their experiences and, where the organisation of the school day allowed, small focus groups of students were interviewed. These semi-structured interviews were audio recorded.

3.4.5 Teachers' logs

Each teacher was asked to keep a brief log of their use of the system, noting which of TI-Nspire™ Navigator™ functionality they had used. This log recorded all of the teachers' uses over the period of the project.

3.4.6 Teachers' questionnaires

The pilot teachers completed email questionnaires in April 2008 and June 2008 probed how they were beginning to use TI-Nspire™ Navigator™ and identify any logistic or technical issues in relation to this usage.

- What successes have you had so far? - Describe briefly
- What issues have you experienced? - Have you managed to overcome these issues?
- Do you have any recurring technical issues?

3.4.7 Data coding scheme

Each school was given a one or two letter code (See Appendix 11.5) and each teacher was identified by the two initials of their first and last name. Each lesson was numbered by the teachers in the order in which it was taught. For example, the first lesson taught by Cindy Hunt of Davison School is coded DCH1.

3.5 The data analysis process

3.5.1 Stage 1: Frequency of use of the various TI-Nspire™ Navigator™ features

The data analysis was carried out in two stages. In the first stage all of the lesson components were scrutinised and, from the data provided, the use of each of the TI-Nspire™ Navigator™ features was logged to enable a quantitative comparison of their frequencies of use to be made. This data was summarised in an Excel spreadsheet (See Appendix 11.8).

3.5.2 Stage 2: Nature of the use of the various TI-Nspire™ Navigator™ features

The second stage of the data analysis involved extracting the descriptive comments of the teachers' uses of the various TI-Nspire™ Navigator™ features from the data for each lesson. These were then classified using a grounded theory approach to elicit a set of categories of use and the teachers' supporting rationales for this use. Implications for the use of TI-Nspire™ Navigator™ were also revealed by this methodology.

3.6 The role of the researcher

The researcher has had considerable experience of supporting teachers to develop their classroom uses of new technologies through a 'researching-with' approach that supports the development of the teacher's own research expertise. The researcher's experience includes:

- involvement in one of the first pilot projects involving handheld technology in England (Stradling et al. 1994);
- authoring classroom activities and resources (Galpin & Graham 2001);
- authoring and contributing to television programmes, books and guidance documents for teachers on the use of ICT in mathematics (British Educational Communication and Technology Agency 2008; Clark-Jeavons 2005a; Clark-Jeavons 2005b; Clark-Wilson in press; Teachers TV 2008);
- authoring teacher development materials involving both handheld and computer technology for mathematics (Department for Education and Science 2003).

Consequently, the researcher supported the teachers by:

- seeding the project with rich mathematical starting points that could exploit the TI-Nspire™ Navigator™ functionality in interesting ways;
- supporting teachers to develop TI-Nspire™ activities for use with TI-Nspire™ Navigator™;
- providing feedback on lesson plans and evaluation reports;
- staying sensitive to individual teacher's levels of confidence with their own mathematics subject knowledge, pedagogical boundaries and use of the technology.

3.7 The approach to the professional development

Establishing the sense of community for this project was seen as an essential foundation on which we could build the participating teachers' sense of being both supported and valued. This had been an important feature in the preceding TI-Nspire™ evaluation research project, and it was deemed important that the project maintained a clear sense of "researching-with", which had come about by the privileging of the teachers' classroom stories.

Although the timescale for this evaluation was short, it was considered important that the teachers had an opportunity to meet each other and share their initial experiences with TI-Nspire™ Navigator™. This was achieved through a one-day meeting in London in May 2009.

3.8 Ethical considerations

In conducting this research study, the ethical guidelines laid down by the British Educational Research Association (2004) were followed. All respondents agreed to the inclusion of their own and their school's names within this final report.

4 Findings

4.1 Introduction

The analysis of the teachers' lesson evaluations and the supporting data enabled a range of categories of uses for TI-Nspire™ Navigator™ to emerge. Many of these were not mutually exclusive in that they touched on several aspects of the TI-Nspire™ Navigator™ functionality. For example, a single lesson might integrate the use of a number of TI-Nspire™ Navigator™ features and the teacher may not attribute the noticeable outcomes to any one particular aspect.

4.2 Teachers' perceptions of the TI-Nspire™ Navigator™ system

The most obvious finding of this evaluation research has been the overwhelmingly positive response provided by the teachers with respect to the way in which the TI-Nspire™ Navigator™ system has enhanced their students' experiences as well as their own teaching and had supported their use of TI-Nspire™ in the classroom. Although all of the teachers acknowledge ways in which they want to develop both their classroom practices with TI-Nspire™ Navigator™ and the design of TI-Nspire™ lesson activities, there were no examples provided where teachers felt that the use of TI-Nspire™ Navigator™ had not had a positive impact on their classroom practices in some way.

The facility to send pre-constructed files to students' handhelds using TI-Nspire™ Navigator™ was used in 80% of the reported lessons and it should be noted that, in the remaining 20% of lessons, it was not actually appropriate to use a pre-constructed file since the lesson activity required the students themselves to design the TI-Nspire™ file they were going to use. This implies that all of the teachers found this facility to send files an easy process to use. Although only two of the teachers specifically mentioned the File transfer facility as a particular advantage of the TI-Nspire™ Navigator™ system, I would hypothesise that this low number is because other features of the TI-Nspire™ Navigator™ system proved to be more pedagogically and mathematically interesting to the teachers such that file transfer very quickly became a normal part of their practice.

The teachers revealed some of their early perceptions of the potential for the TI-Nspire™ Navigator™ system through their responses to a task that they completed during the one day meeting in London in May 2009. These responses are summarised in Appendix 11.6.

4.3 Frequency of reported use of TI-Nspire™ Navigator™ features

The analysis of the frequency of use of the various TI-Nspire™ Navigator™ features is shown in Figure 4.1. This data was concluded from the lesson analysis in Appendix 11.8, which means that a ‘use’ is counted as once for each lesson, even though it may have been used several times within any given lesson.

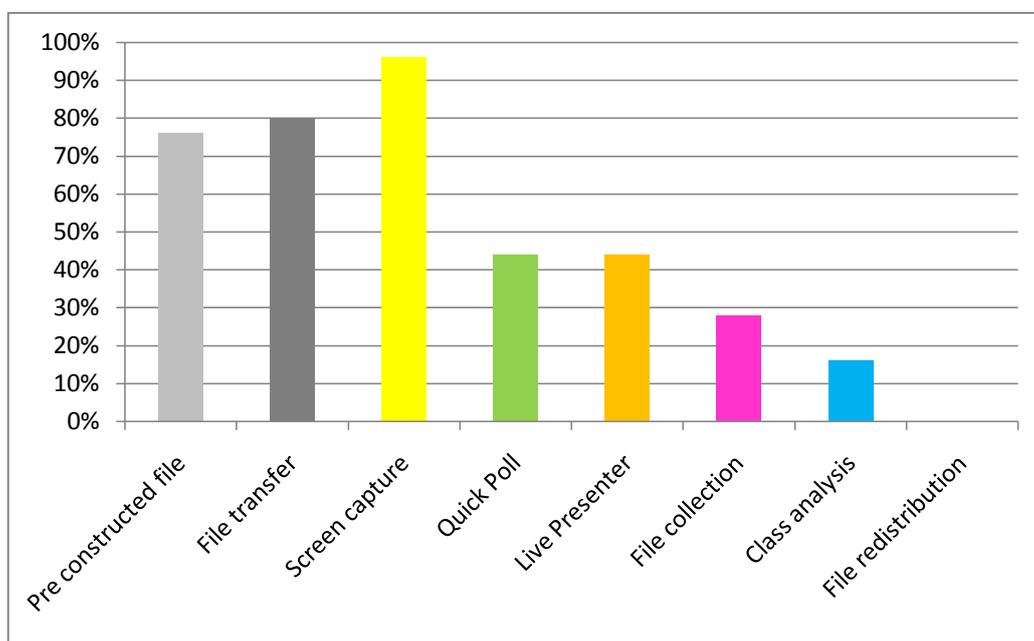


Figure 4.1 Frequency of use of TI-Nspire™ Navigator™ features (n=25)

4.4 Use of Screen Capture

4.4.1 Introduction

Screen Capture was easily the most popular feature of TI-Nspire™ Navigator™ and it was used in 92% of the lessons with the teachers unanimously reporting very positive outcomes of its use in their classrooms. The data analysis led to the following categories of use:

- monitoring students activity during the lesson;
- supporting teachers to know when to intervene;
- promoting and initiating whole class discourse;
- promoting and supporting peer- and self- assessment;
- privileging mathematical generalisation;
- increasing sample sizes (within statistical work);
- enabling mathematical sorting.

What follows is a description of each of these usage categories with exemplification from the pilot classrooms.

4.4.2 Monitoring student activity during lessons

All of the teachers reported that the use of Screen Capture had enabled them to monitor students' activities whilst they were working with TI-Nspire™ during lessons. The rationale for this monitoring varied, with some teachers using this functionality in a passive way to check 'that every student is working – doing what they were supposed to do' [AIPR1] and 'to ensure that everyone got to the first page okay' [GNH3]. There were a small number of lessons where the teachers used Screen Capture privately on their own computer (e.g. LBW3, whilst the students were completing a test). However, in the vast majority of lessons the Screen Capture display was on public view in the classroom. This prompted a much more active use about which the teachers were highly enthusiastic, namely the insight that Screen Capture gave into how their students were engaging with the tasks they had been set.

Some teachers said that they were monitoring the students' work for pace, both to observe the students' natural work rates and to impose an expected work rate. One teacher said it was to 'spur on the learning' [DCH2(LEval-T)] and another 'to selectively sample the class work and drive the activity forwards by challenging them with new situations they had constructed' [GNH3(LEval-T)]. One of the notable comments made by several teachers related to an appreciation that the pace at which their students worked was much more widely distributed than they had previously appreciated.

Several teachers commented specifically on the value of Screen Capture as a window into their students' progress through the lesson. In one lesson evaluation, Jay commented,

Screen Capture gave me instant feedback throughout regarding student progress. As a teacher you develop a sense of how a lesson is progressing based on the level of noise, the snippets of conversation that you hear, etc. However, in this lesson I was able to 'see' what students were doing. This adds to the other sensitivities that I have so that I am able to make better judgments. [BJT2(LEval-T)]

Other teachers reported that they were monitoring specifically for the purpose of identifying exemplar solutions and common (or particular) mistakes, which in some cases led to an individual or whole class intervention by the teacher.

4.4.3 Supporting teacher interventions

In all cases, the reported use of Screen Capture led to some action or intervention on the part of the teacher. These ranged between interventions involving individual students (or groups of students) to the initiation of focusing activities involving the whole class.

By far the majority of teacher interventions related to those of a pedagogical and mathematical nature concerning the task itself. In many cases the teachers used the initial Screen Capture view to identify particular students (or their screens) as the focus for the whole class discourse. In some cases this led to the identification of one student to become Live Presenter ([AvMW3], [DCH3], [SEvW2], [AIPR(Log-T)]) and in other cases to highlight particularly interesting solutions or responses ([LBW3], [BJT2], [DCH3]).

Some teacher interventions following the use of Screen Capture arose from their observation of issues the students were experiencing with their use of the TI-Nspire™ files. For example ‘I adjusted my advice for how to keep the triangles on the screen by reducing all of the lengths to smaller numbers’ [GNH4(LEval-T)] and ‘I had to use Screen Capture to see why they did not find any connection... I could see they had dots everywhere so I had to resend the file.’ [AIPR1(LEval-T)]. This also supported the teachers to appreciate issues within the design of the TI-Nspire™ file by ‘learning from how the tns file was interacted with and what things could too easily be ‘broken’ with it’ [GNH4(LEval-T)].

There was evidence in their lesson evaluations to suggest that, as the project progressed, the teachers were becoming more aware of knowing when to intervene and who to intervene with and also used the information from Screen Capture to inform them as to when the students were ready for them to progress with the lesson content.

4.4.4 Promoting whole class discourse

A common reason cited by the teachers for the use of Screen Capture was with the intention that it would promote discussion and communication in the classroom [GNH4], [AvPR1], [BJT1]. The outcomes of this were positively reported by Epi, who said ‘Seeing each others’ work gave a wider discussion through the class than what normally happens between students seated next to each other’ [SEvW1(LEval-T)]. The nature of this discourse varied. In the observed lessons it tended to be a more teacher dominated discourse of instruction and explanation, but there was evidence in two classrooms of the teacher using the Screen Capture view to prompt them to ask the students to discuss amongst themselves prior to feeding back their thoughts to the whole class.

4.4.5 Promoting and supporting peer assessment

The diversity of student outcomes that Screen Capture made public resulted in several examples from the classrooms in relation to the opportunities for both peer- and self-assessment. The following quotes provide rich evidence:

- The students could ‘learn from each other and see their mistakes’ [AIPR1(LEval-T)];
- ‘Some students also watched to get ideas and support’ [AvMW3(LEval-T)];
- ‘The sharing of thoughts at the half-way stage led in several cases to students checking some of the declarations that had been made by their peers’ [GNH5(LEval-T)];
- ‘It is really fantastic to see how much the students learn by just looking at each other on Screen Capture’ [AIPR3(LEval-T)]

Other teachers were more specific about how the use of Screen Capture had supported the students to communicate their mathematical ideas and associated thinking, again leading to improved responses as a result of viewing the responses of their peers.

4.4.6 Privileging mathematical generalisation

An initial aim for this pilot study was to actively encourage the teachers to consider the mathematical topics for which sharing a variety of students' responses would have a clear mathematical purpose. The teachers responded to this challenge very positively and some rich mathematical examples were generated. ([SevW1], [AIPR3], [AvMW2], [BJT1], [BJT2], [DCH1], [DCH2], [DCH3])

The underlying principle for all of these tasks was to create a shared learning space through which all students' contributions contributed to the 'big picture' and, with careful teacher questioning and prompting, the students were able to make sound mathematical generalisations. The sort of mathematical aims that the teachers proposed were for students to explore the function family $y=a^x$ 'to see how the value of a will have a different impact on the graphs' [AvMW2(LEvalT)] and 'that there are infinite number of straight lines through a certain point' [AIPR3(LEvalT)].

The major feature of these lessons was the emphasis on similarity and difference (two fundamental mathematical concepts) and the teachers made particular comments in relation to both of these with respect to how Screen Capture facilitated a new approach to the mathematics:

- 'After some exploration there were 16 screens with all different situations' [SEvW1(LEvalT)];
- I wanted the students to 'see the different lines that they had all drawn through the same point' [AIPR3(LEvalT)];
- I wanted Screen Capture to 'show a variety of results... the idea being that we could all see that right angled triangles gave the right solution' [DCH3(LEvalT)];

Epi justified this approach by saying 'I needed every student to see many different screens to come to the generalisation. If they only see their own screen they lack a global view.' [SEvW1(LEvalT)]. In these examples Screen Capture enabled the use of the shared learning space to focus the students on the common part of the task. This sense of a collaborative learning environment was captured by Nevil who wrote, 'We are in this together – the knowledge is shared – not 25 individuals' [GNH2(LEvalT)]. Several of the teachers commented that they would be keen to further develop the mathematical TI-Nspire™ activities which would exploit this use of Screen Capture.

4.4.7 Increasing sample sizes (within statistical work)

An interesting mathematical use of Screen Capture emerged from three lessons ([LBW1], [IBW2], [GNH2]) in which the Screen Capture view was used with purpose within lessons involving work in statistics. In these three cases the teachers explicitly commented on how the mathematical relevance of sample size could be promoted to the class by seeing everybody's data. In one case this was 'to show that when students showed the same RandSeed number, all screens in the next Screen Capture showed the same random number' [LBW1(LEvalT)]; and in another to 'take a snapshot of how many students were getting a better estimate – to tally up-front' [GNH2(LEvalT)];. This suggests a potential use of Screen Capture which might be worth developing further within the design of TI-Nspire™ activities for use with TI-Navigator™.

4.4.8 Enabling mathematical sorting

One lesson attempted to use the students' Screen Capture displays as objects for sorting into those which did and did not have a particular mathematical feature [BJT2]. However, the current functionality of TI-Nspire™ meant that, as the screens automatically 'snap to grid' it was not so easy to make obvious to the students where the boundaries of the groups lay as the screens were continuously reordered in fixed grid layout. This also highlighted the facility to colour code the individual screens as an alternative way to draw attention to particular mathematical features as potential future functionality within Screen Capture view.

4.5 Use of Live Presenter

Live Presenter proved to be a popular feature of TI-Nspire™ Navigator™ and was used by all but one of the teachers. This teacher had rejected its use as he felt that the refresh rate was too slow and, given the immense time pressures he was under with lesson lengths of just 40 minutes, he wrote, 'with finite time I am probably the best source' [GNH2(LEval-T)].

The categories of use sub-divided into 'use by teachers' and 'use by students' and included:

- teacher and student use to support the use of the TI-Nspire™ handhelds;
- teacher use to introduce and develop the mathematical tasks;
- teacher use to generate data for use by the class;
- student use to share mathematical observations, outcomes and insights.

4.5.1 Supporting the development of students' TI-Nspire™ skills

A number of teachers were very enthusiastic about the facility to use a handheld to log in themselves or make themselves the Live Presenter with the specific intention of demonstrating particular TI-Nspire™ functionality to the students [AvMW2], [AIPR3], [BJT2]. This support ranged from helping students to 'see where to find the file and how to open it' [AIPR1(LEval-T)] to showing students how to 'do the graphs and change the values' [AvMW2]. Other teachers did not actually manipulate the TI-Nspire™ software directly themselves, but invited or chose students to become Live Presenter and talked through the necessary steps.

Petra wrote very positively about why she chose to make a student Live Presenter, rather than lead a demonstration herself,

I put very often up a student as live presenter instead of me because then the rest of the class can follow more easily. If I am the live presenter I know exactly what to do and then it often goes too fast so the students have problems in finding the right buttons etc. If I put up a student as a live presenter he or she often gets help from the whole class and we often get a very good discussion. [AIPR(Log-T)]

This approach was also adopted by Bert, who wrote that by 'making students Live Presenter, they explained to each other where to find the different menu commands' [LBW1(LEval-T)]. A variation on this strategy was

developed by Bert who made one student the Live Presenter and asked another student to talk through the process of creating a pie chart from a list of raw data [LBW4].

4.5.2 Supporting the introduction and development of the mathematical tasks

Whilst this often overlapped with the introduction of the TI-Nspire™ skills, several teachers commented on how they used Live Presenter to focus students' attentions on the mathematics of the task for example 'to discuss all of the different types of linear functions that went through a point' [AIPR3(LEval-T)]. In some cases this was in response to particularly interesting student work that had been identified by Screen Capture. Generating data for use by the class

An innovative use of Live Presenter was developed by Maria, who adapted her 'tried and tested' use of the temperature probe to capture real data for mathematical modelling by connecting her own handheld to the GoTemp probe and displaying the data capture through Live Presenter. She was then able to save the file on her handheld and send it directly to the class using TI-Nspire™ Navigator™.

4.5.3 Student use of Live Presenter to share mathematical observations, outcomes and insights

A number of teachers selected students to be the Live Presenter to enable them to share strategies, approaches and findings that related to the mathematics itself:

- 'I had a student who just summarised the impact of different values of a ' [AvMW2(LEval-T)];
- 'I asked a student to explain *What are you moving?*' [DCH3(LEval-T)];
- 'I made one student Live Presenter so that she could make up a question for the class' [BJTLog];
- 'I made students Live Presenter and let them explain their theories' [SEvW1(LEval-T)].

Whilst students were acting as Live Presenter, there were several occasions where the teacher intervened with particular questions or instructions to develop the students' TI-Nspire™ skills and support their understanding of the mathematics. For example, Epi instructed the presenting student on how to rotate a linear function in order to test a particular conjecture that the student was making.

It was noticeable that there appeared to be greater reported use of Live Presenter by students from the teachers in the Pilot classes where the students had experienced unlimited access to their own TI-Nspire™ handheld. It did appear that they had a greater familiarity with the key and menu locations. However, as these same students were also: the oldest students in the study; the most able mathematicians; and many of these students had been using the TI-Nspire™ handheld for a longer length of time; there is insufficient data to support any causal link.

4.6 Use of Quick Poll

Quick Poll was used in 11 of the reported lessons, and although no particular trends in use emerged from this fairly limited data, the range of uses for Quick Poll included:

- as a focusing act to initiate the start of lesson activities;
- the generation of data for use during the lesson;
- prompting class discussion on a particular mathematical feature, concept or fact;
- checking students' understanding of a particular mathematical feature, concept or fact;

What follows are examples of all of the different uses that emerged during the pilot.

4.6.1 Initiating the start of lesson activities

There was one example where the teacher used Quick Poll to mark the beginning of the lesson activity, 'Are you ready for the revision of exponential functions?' [AvMW3(LEval-T)] and another where the teacher had sent a Quick Poll saying 'Look at the board now' [BJTLog]. In one case Quick Poll was used to poll the students on the direction of the lesson itself, 'I used a quick poll to find out which students wanted me to show them how to work out the limit using algebra' [GNH5(LEval-T)].

4.6.2 Generating data for use during the lesson

Cindy used Quick Poll to initiate the mathematics task for the lesson, which was to explore the graphs produced by coordinate points, by asking the students to 'Give me two numbers when squared and added together give me 25' [DCH2(LEval-T)]. The Quick Poll was set up to accept open responses and Cindy justified this use by saying that she wanted to 'promote individual thought' [DCH2(LEval-T)]. Figure 4.2 shows their responses.



Figure 4.2 Using Quick Poll to generate coordinate points that satisfy $x^2+y^2=25$

In her lesson evaluation, Cindy commented,

The responses were then shared with the whole class and we scrolled down each one and comments were made about the results. I had given no guidance as to how to share solutions so there was a big array of answers. The majority included 3 and 4 as I had expected. A very few students had included zeros (are they allowed I was asked?) Also one or two students included negative values. This prompted more discussion as to the values that were allowed. I then got them thinking in terms of x and y and constructing a graph of results.' [DCH2(LEval-T)]

The students then continued to work individually on the activity on their handhelds, which was to populate a Spreadsheet with the pairs of numbers and observe the resulting graph being drawn on an adjacent Graphs and Geometry page. Cindy concluded that the use of Quick Poll in this way had been a 'brilliant start as a platform to the lesson' [DCH3(LEval-T)].

4.6.3 Prompting class discussion

Two teachers described their use of Quick Poll as providing an opportunity to initiate (or finalise) a class discussion on a particular mathematical feature, concept or fact. Maria found this a highly informative process and concluded, 'By using quick poll and my few questions about the domain, range and the asymptote I think the students really understood these concepts' [AvME2(LEval-T)]. Petra concluded that this process greatly supported the students self and peer assessment as she allowed the answers to be visible to the class before everyone had answered because 'they can learn what to do by looking' [AIPR3(LEval-T)].

4.6.4 Checking student understanding

A similar but subtly different use was to use Quick Poll to enable the teacher to assess more explicitly their students' understanding on a particular mathematical feature, concept or fact. For example, Bert wrote that he used it 'for interrupting the students and ask them some questions on the theory' [LBW1(LEval-T)]. In one of his lessons Nevil had observed from Screen Capture that the students were undecided on whether knowing the three side lengths of a triangle would be sufficient information to define it as a unique triangle. He wrote 'It was not clear that everyone was seeing the key issues so I did a Quick Poll... .. to find out where they all stood on the issue of the three sides' [GNH3(LEval-T)].

4.7 Use of Class Analysis

There were four reported uses of the Class Analysis functionality to analyse students' responses to questions that had been embedded within the students' TI-Nspire™ file. In two of these lessons the questions were answered by the students, the file collected by the teacher, then the results analysed within Class Analysis and displayed to the students during the same the lesson [DCH3 and GNH1]. In the third lesson the teacher wrote, 'The class will end by [students] answer[ing] three questions which will clearly show if they have grasped the maths.' [AvMW1(LEval-T)].

One of the teachers who adopted this strategy supported this approach by saying,

'Running the quick quiz of 3 questions, then collecting these in, then talking about them, and none of this interrupted the pace at which they progressed with the task, was good. It also added a bit of variety to the lesson in that we went over their submitted answers a short time after they had completed them, and hence they were still fresh in their minds, yet they had had as long as they needed to answer them.' [GNH1(LEval-T)].

This teacher went on to suggest that the Quiz ⇒ Start task ⇒ go over Quiz ⇒ Continue task was a model that he would develop for other lessons.

The teachers used a variety of strategies when formatting their questions, with several adopting the question formats that required a 'true-false' and 'always-sometimes-never' response. One teacher commented explicitly on how the students' responses had not been as expected and that she would need to develop the students' ability to both interpret and respond to such questions, as this was not normally part of her existing classroom pedagogy.

4.8 Use of File collection and redistribution

There was very little reported use of File collection by the teachers during the study for either assessment purposes or in order to redistribute files at the beginning of the next lesson, with only one teacher mentioning use of this functionality. He commented on how he felt that it had motivated the students to record their mathematical conclusions to the task they had been working on, 'They know that I was going to collect in their

notes, so I think they put more effort into writing up their thoughts clearly than they might otherwise have done' [GNH4(LEval-T)]. In a couple of cases, when the researcher was present in the classroom, an unprompted file collection was made in order to capture the students' TI-Nspire™ files for research purposes.

The teacher who did make use of file collection and redistribution commented that he had experienced issues with respect to dealing with students' absences. For example, if a student was not present in the initial lesson when the file was first distributed, the system did not automatically detect by sending the relevant file to enable them to begin the task. They would have to be dealt with on an individual basis, which could potentially disrupt the beginning of the lesson, as the teacher took time to ensure the returning student would be able to participate in the lesson.

4.9 Summary

The project data has revealed a diverse set of emerging practices by the teachers and it is important to stress that no one teacher (or lesson) incorporated all of these. In all cases the teachers identified ways in which, by learning about what the other teachers were doing, they would widen their pedagogical approaches and begin to plan lessons with more explicit and deliberate uses of some functionality.

For example, Maria commented that she wanted to 'Use students as Live Presenters to encourage some students and guide others in a direction so that they all can do the activity faster' [AvMW3(LEval-T)].

Most of the teachers commented in their lesson evaluations and teacher's logs that they particularly wanted to develop their use of Quick Poll during lessons. Teachers were aware that they were not maximising the pedagogical opportunity that it offered and suggested pedagogical strategies such as:

- In future 'I would use a few Quick Polls to get a discussion and build a concept' [AvMW2(LEval-T)];
- 'Perhaps I will use Quick Poll to check that the students have understood the task and found out the right connection afterwards' [AIPR1(LEval-T)];
- In future 'I would use Quick Poll more often' [LBW1(LEval-T)].

One teacher did raise the point that, in planning to use Quick Poll, the lesson did need to be well-prepared as the teacher needed a sense of which questions to ask and when. The teacher also needed to anticipate a range of students' responses and have devised some pedagogical strategies in response to these.

5 Discussion: What are the emerging features of teachers' uses of TI-Nspire™ Navigator™?

5.1 Introduction

The analysis of the emergent practices that the teachers developed using TI-Nspire™ Navigator™, supported by the teachers' rationales for these uses, revealed the following themes:

TI-Nspire™ Navigator™ was used to:

- develop new and support existing formative assessment practices;
- enable the development of innovative mathematics tasks;
- support teachers' lesson planning to include desired pedagogical approaches, lesson organisation and classroom management strategies;
- support the use of the TI-Nspire™ handhelds for individual and whole-class work.

5.2 TI-Nspire™ Navigator™ supporting the formative assessment of mathematics

For the purposes of this report, the definition of formative assessment provided by Paul Black and Dylan Wiliam (as an outcome of their extensive research into teachers' classroom practices over the last two decades) has been adopted,

Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited. (Black & Wiliam 2009, p.9)

There was resounding evidence from the teachers' lesson evaluations and the accompanying lesson observations that TI-Nspire™ Navigator™ provided an opportunity for the teachers and students to engage in a range of formative assessment practices.

These practices could be described as:

- providing teachers with additional insight to enable them to provide thoughtful interventions during the lesson;
- promoting purposeful classroom discourse to enrich the teacher's awareness of students' existing mathematical knowledge;
- developing strategies for students' peer assessment and self assessment.

Each of these practices is now described in further detail, supported by evidence from the research data.

5.2.1 Supporting thoughtful teacher interventions

A variety of evidence about the ways in which the teachers used TI-Nspire™ Navigator™ system to support them to know when their interventions were needed in order to progress the students' mathematical learning was elicited.

- Screen Capture was used by the teacher to monitor students' work and identify both mathematical and TI-Nspire™ issues 'before they escalated'. Teachers were then able to target appropriate (differentiated) support either to individual students or the whole group, as appropriate.
- In response to identified observations of students' difficulties, teachers were able to 'help more students at a time' using Live Presenter.
- In response to particular mathematical observations from Screen Capture, Quick Poll questions were sent to students to check opinions, facts and conceptual understanding.
- Screen Capture was used by the teacher to identify 'interesting screens' that could be used to increase students' active engagement in the lesson through the use of Live Presenter by identified students.

Very few of the teachers progressed to using Class Analysis to assist their formative assessment practices between lessons, for example by reviewing TI-Nspire™ files collected from the students' handhelds, analysing embedded question responses and planning the next lesson's activities based on this information, or sending feedback to students within redistributed TI-Nspire™ files. This is not necessarily because they did not think it would be useful. Indeed, two teachers commented that they knew it would be helpful but they did not necessarily know how best to deal with this additional information about their students' achievements. This implies a professional development need for teachers to allow them to consider how to make the best use of the extra information about their students' mathematical understanding when planning the subsequent lessons.

5.2.2 Promoting purposeful classroom discourse

All of the teachers cited at least one example of how the use of TI-Nspire™ Navigator™ had supported the quality of the mathematical discourse within the lesson. The term discourse refers broadly to the words that are spoken in the classroom by teacher and students, the nature of which can vary greatly from classroom to classroom. For some teachers, the aim was for this discourse to be less teacher dominated, where only one or two students respond to the teacher's questions. This could be achieved by including more opportunities for discussion by the students. For example, by asking students to discuss an aspect of the mathematics observed through the Screen Capture view with a fellow student and be prepared to feedback their opinions or hypotheses. The visibility of many TI-Nspire™ screens provided more to discuss in the classrooms and Quick Poll or embedded questions within the TI-Nspire™ files were also used to prompt the discourse.

5.2.3 Supporting peer and self assessment strategies

Within the context of Black and William's definition of formative assessment, students' peer and self assessment approaches include all of those practices whereby students position their own knowledge and understanding alongside those of their peers and, as a result of being exposed to other students' views and opinions (as well as the teachers), reposition their stance. The use of Screen Capture alone provided substantial evidence for how exposing students to the thinking of their peers, as evidenced by the snapshots provided in the Screen Capture view, had a noticeably positive impact on the students' lesson outcomes. Although this study was not designed to seek evidence of improved students' outcomes in mathematics, the teachers reported many examples where they noticed that students changed their opinion or moderated their responses as a result of both the passive and active sharing of students' outcomes. In the passive instances, Screen Capture was just displayed publicly in the background and students were free to look at it or ignore it. In the more active scenario, the teacher drew students' attentions to 'interesting screens', sometimes asking the owner of selected screens to share their thinking. In both scenarios this provided opportunities for students to learn from their peers.

Quick Poll and Class Analysis responses and results were used publicly in a similar way to enable individual students to learn from the responses of others. One teacher commented on how allowing her students to see each others' responses (correct and incorrect) specifically supported the less mathematically confident students, as they were able to see that they were not the only students who were unsure how to respond.

5.3 TI-Nspire™ Navigator™ supporting the development of innovative tasks and approaches for mathematics

During the pilot project a number of tasks were designed and pedagogic approaches devised which used the TI-Nspire™ Navigator™ features in innovative ways, in some cases eliciting new approaches for mathematical tasks which would not have been possible using existing resources for mathematics.

5.3.1 Focusing students' attentions on making mathematical generalisations

The most exciting of the innovative approaches developed for the use of TI-Nspire™ Navigator™ related to the development of a number of tasks where Screen Capture was used to support students to arrive at mathematical generalisations. In these activities, the teachers had constructed TI-Nspire™ files which required the students to change specific variables by dragging on-screen objects to meet certain constraints. These activities were mainly graphing and geometric tasks as the screen view needed to contain something that was visible to the class when the Screen Capture view was displayed. The resulting screens supported the teacher and students to notice similarities and differences between the various outcomes and to focus on the common mathematical features or aspects of the task. The wide variety of responses provided both a global view of the mathematics under scrutiny in addition to the individual student's local view.

One teacher's attempt to try to sort the individual screens as displayed in the Screen Capture view to identify those that did and did not meet a specific mathematical constraint highlighted an issue with the grid arrangement of the screens, which prevented this from being a useful pedagogic strategy. The researcher also identified that an alternative approach using colour coding might also be desirable additional functionality.

5.3.2 Creating a 'shared learning space'

Several teachers were very enthusiastic about the way that the use of Screen Capture supported the notion of a 'shared learning space' in which each student had a sense of ownership with respect to their own screen and an appreciation of how their screen fitted into the bigger picture or 'global view' previously mentioned. This view was supported by several of the students interviewed, one of whom said 'We feel good to be seen in the screen by the all class. It is a bit embarrassing if you are wrong but we are human beings. I [We] can be supported by friends if I'm wrong' [AIPR(Int-S)]. Another student said 'You really want to know who you are in the screen capture' [AvMW(Int-S)]. It was noticeable that, in the pilot classes, Screen Capture was used with the students' names showing, enabling both the students and teachers to know whose screen was whose. A consequence of this shared learning space was that the teachers were able to open Live Presenter in order to take up the students' own suggestions with respect to the task and this also seemed to encourage the students to begin to pose their own mathematical questions. One teacher gathered responses from his whole class about their perceptions of the TI-Nspire™ Navigator™ system, which also provided good evidence of the students' appreciation of how seeing each others' screens supported their learning (see Appendix 11.9).

5.3.3 Generating data for use during the lesson

There were two examples where TI-Nspire™ Navigator™ had been used to generate the mathematical data to initiate the task with which the students were to engage. In one example Quick Poll was used to elicit students' responses to an open mathematical question to enable a wide number of answers to stimulate the students' thinking. In the second example the teacher's handheld was connected to a temperature probe and Live Presenter used to carry out a data collection experiment at the beginning of the lesson. File transfer was then used from the teacher's handheld to distribute the data quickly and efficiently to the students' handhelds and facilitate a mathematical modelling task.

5.3.4 Increasing the visible sample size within statistical work

Two teachers provided examples of the use of TI-Nspire™ Navigator™ to enhance statistical work in mathematics by using the Screen Capture view to increase the visible sample size of the class data. This was used to support students' understanding of the relevance and importance of sample size when drawing assumptions from statistical data and also to appreciate the way in which the TI-Nspire™ Random number generator and RandSeed setting influenced the resulting data when simulating dice experiments. One of the teachers commented that 'the *capture everyone's simulation results graphically* approach is a route I'd be interested in seeing if there are other topics of maths that could benefit from this sort of approach'.

5.4 TI-Nspire™ Navigator™ supporting the use of the TI-Nspire™ handhelds

There was very strong evidence from the lessons of the use of Live Presenter in particular to support the use of the TI-Nspire™ handhelds in the classroom. There were a range of models for this use, the most common of which was the use of Live Presenter by the teacher to demonstrate TI-Nspire™ skills such as locating and opening files, moving between Problems and pages, navigating menus, entering information and grabbing and dragging on-screen objects. Alternatively, teachers made the students the Live Presenter to allow them to demonstrate their own approaches with TI-Nspire™ – to produce statistical graphs, for example. There was one teacher who used an aspect of the ‘Sherpa student’ approach² (Guin & Trouche 1999) whereby the teacher made a chosen student the Live Presenter and instructed the student with the key presses to produce the desired outcome.

5.5 TI-Nspire™ Navigator™ supporting the planning and organisation of lessons

The most significant feature of TI-Nspire™ Navigator™ which enabled a smoother lesson start and supported the use of a higher proportion of pre-constructed TI-Nspire™ files was the File transfer facility. One teacher commented that this allowed final changes to the TI-Nspire™ file to be made up to five minutes before the lesson and, in the case of one lesson where some rogue data in the Spreadsheet had hindered the students’ progress, the teacher was able to amend the file and send a second version to the students during the lesson.

The lessons which integrated a number of TI-Nspire™ Navigator™ features had been carefully planned to include the use of thoughtful Quick Poll or embedded questions and a consideration of what the students would be doing at all stages in the lesson. For example, in one lesson the teacher collected back the TI-Nspire™ files midway through the lesson to enable him to process the embedded questions within Class Analysis, with the sole purpose of identifying the common questions that students had found difficult and in order to revise the necessary mathematical content with them. As he knew this would take a couple of minutes, he had planned a related paper and pencil task for the students to engage with, ensuring purposeful use of this time.

Most of the teachers used Live Presenter themselves to introduce the TI-Nspire™ task that the students were going to be working on. The teachers were positive about this and mentioned that the transition to the student activity was smoother than in previous lessons when they were using TI-Nspire Teacher Edition™. This might be because Live Presenter offers a closer replication of the student’s task, with key presses highlighted, but might also be because the interface was slower, thus preventing the teachers from moving too quickly.

The majority of teachers referred to the way in which the use of features such as Quick Poll, and the facility to analyse students’ responses to embedded questions using Class Analysis, required them to plan their lessons

² The ‘Sherpa student’ describes an approach with TI-92 handhelds and an overhead Viewscreen whereby the student acts as an assistant, mediator and guide for the class by operating the technology.

more thoroughly. Although this required a considerable investment of their time initially, they saw themselves building a bank of TI-Nspire™ tasks for use with TI-Nspire™ Navigator™ that they could adapt for future classes.

Two teachers used the Quick Poll feature to support the management of the pace of the lesson by polling students to gain their attention at key times and, in one case, polling the students on the direction that they wanted the lesson to take.

The information provided by Screen Capture was used (privately and publicly) to enable teachers to know when to move on to the next stage of the task and, in a lesson that integrated the use of Class Analysis, to know when to collect back the TI-Nspire™ files from the students.

The extra insight that the teachers gained from the use of Screen Capture also supported the modification of the TI-Nspire™ files as the teachers recognised difficulties that the students had experienced. Such modifications included the choice of Question template used, the presentation of the activity on the TI-Nspire™ screen and in one case, a redesign of the initial task.

5.6 Emerging issues relating to the classroom use of TI-Nspire™ Navigator™

Although, as previously stated, the classroom evidence provided by the teachers was resoundingly positive about TI-Nspire™ Navigator™, there were a number of issues that emerged that are worthy of a deeper discussion. These issues do not include the technical functionality issues relating to the TI-Nspire™ Navigator™ system, for example problems logging on and lost connections, as these were reported separately to the Texas Instrument's technical team.

5.6.1 Use of File collection, Class Analysis, and File redistribution

An initial response to the usage graph of the TI-Nspire™ Navigator™ features (See Figure 4.1) could conclude that the teachers did not see much use for File collection, Class Analysis and File redistribution. However there are a number of important contextual factors that might explain this low usage.

- It is possible that, in the countries involved in the pilot, the teachers do not habitually collect class work from their students to assess at the end of the lesson and/or to inform the teacher's planning and preparation for the next lesson. Both the English and Dutch teachers said that normally they only formally assess homework and tests. This implies that professional development might be needed to highlight how the use of TI-Navigator could support teachers to plan subsequent teaching that is more closely aligned to their students' needs by developing their use of Class Analysis.
- The teachers felt that they had gained a substantial amount of information about their students' progress during the lesson by just using Screen Capture and that they did not need to collect back the students' files.

- As most of the teachers were only a few weeks into their use of TI-Nspire™ Navigator™, they had not had a chance to develop how they might use File collection, Class Analysis and File redistribution and, over time, these practices would develop as part of the typical ‘natural’ development journey with the TI-Nspire™ Navigator™ system.

One teacher wrote that, although he had collected a series of students’ screenshots throughout the lesson, he did not know if and how it would be useful to him. In his evaluation he wrote, ‘the fact that I have ‘taken in’ their work at the stage it’s at and it’s in a form that I can share back with them is something of great potential (but still to be proven). It’s not possible to take in all their jotters, photocopy all of their workings/discoveries and then re-share around the room, which is effectively what’s going on here.’ [GNH6 (LEval-T)].

5.6.2 Managing the change in the classroom ethos

It is undeniable that the introduction of the TI-Nspire™ Navigator™ system to the mathematics classroom impacts upon the learning environment and imposes new ways of working for both the students and the teacher. Several teachers spoke about the need to have the ‘right ethos’ in the classroom whereby TI-Nspire™ Navigator™ was seen predominantly as a tool to support students’ learning rather than for teacher’s monitoring and assessment. Teachers described this ethos in ways which resonated with Hiebert and his colleagues’ definition of an ‘effective’ classroom ethos in which all student contributions are valued, their mistakes are used as learning sites and there is a sense of correctness which resides in the quality of the mathematical argument (Hiebert et al. 1997).

Another teacher spoke of the need to support students to meet new expectations of them in relation to what mathematics is and how they might engage with it. For example, Cindy spoke of her students not knowing how to respond to an ‘always/sometimes/never’ question in a mathematical context and identified that, the next time she used one, she would spend a few minutes discussing with the students how to respond to such a question. In one reported lesson the teacher wrote that a student had asked ‘Is this coming back in the written test’ [SEvW1(LEVal-T)] suggesting that a renegotiation of the didactic contract between the teacher and students was being provoked by the use of the technology.

The teacher who used the Class Analysis feature within a lesson to feedback the outcomes of a class quiz was explicit in telling his students that he was ‘not going to point the finger’ at them but use the results to remind them of mathematical facts that he thought they should already know.

5.6.3 Feedback from other teachers in the pilot schools

Whilst the pilot project did not actively seek feedback from colleagues of the pilot teachers, one of the pilot teachers did share her TI-Nspire™ Navigator™ lessons with her colleagues. She commented,

I have shown some other teachers the equipment and how to use it. They seemed more positive than before. If they can get a whole package of exercises to each course I think they would be even more positive because I think that they think that it is hard to make the activities that

Navigator is perfect for. I also think that if we can make these activities that are ready for the teachers to use, it will get easier for them to see the benefits with this system. [AIPR3(LEval-T)]

5.7 Implications for the role of the teacher

A number of implications for the role of the teacher were identified from the teachers' own writings which were highly reflective and thoughtful on this issue.

Several of the teachers talked about a significant change in their role with respect to managing the mathematics classroom when Screen Capture was being used. One teacher wrote about his slight discomfort about being 'on show' in front of the class more than was usual and another of his perception that he needed to be able to make sense of all the different student responses very quickly in order to plan the next stage of the activity. Similarly, when considering how they might develop their use of Class Analysis, several teachers commented upon the need for them to ensure that they had thought through the students' possible responses and included the right sort of Question and Answer format within any embedded questions..

One teacher wrote early on in the project about how the evidence gained from Screen Capture alone had prompted him to slow his teaching down and that he had realised that the pace at which his students could take up mathematical ideas differed from his earlier perception. This implies that teachers may need support to reconsider their expectations of their students and the implications on the notion of 'pace' when planning their TI-Nspire™ Navigator™ lessons.

5.8 Summary

An indication of the strength of the supporting evidence alongside the emerging uses of the TI-Nspire™ Navigator™ system and its main features is shown in the two-way table represented by Table 5.1.

		TI-Nspire™ Navigator™ feature					
		File distribution	Screen Capture	Live Presenter	Quick Poll	Class Analysis	File collection and redistribution
Formative assessment strategies	Supporting thoughtful teacher interventions	*	***	**	**	**	*
	Promoting purposeful classroom discourse	*	***	***	***	*	*
	Developing peer and self assessment.	*	***	***	**	**	**
Development of innovative tasks and approaches	Focusing student attention on mathematical generalisations	*	***	**	**	*	*
	Creation of a shared learning space	***	***	*	**	*	*
	Generating mathematical data for use during the lesson	*	*	**	**	*	*
	Increasing visible sample size in statistical work	*	***	*	*	*	*
Supporting the students' use of the TI-Nspire™ handheld		***	***	***	*	*	*
Supporting the organisation of lessons		***	***	***	**	*	*

Table 5.1 Overview of the strength of evidence for the different reported uses of TI-Nspire™ Navigator™

KEY:

*** = strong evidence

** = some evidence

* = insufficient data or weak evidence

6 How do these findings compare with the existing research evidence for TI-Navigator™ with TI-84s and TI-Nspire™ ?

6.1 Studies focusing on the use of TI-Navigator™ with TI-84 graphing calculators

The findings from existing research into the use of TI-Navigator™ with TI-84 graphing calculators resonate strongly with the findings of this study. For example, a pilot study on one classroom in Hawaii concluded,

The use of TI-Navigator technology supports the development of a collaborative classroom environment by enhancing student interactions, focusing students' attention on multiple responses, and providing opportunities for students to peer- and self- assess student work. The ability to display a full class set of data or task responses supports a problem-solving approach to developing skills and concepts. (Dougherty 2005, p. 28)

All of these aspects were evident, or emergent within this study, with the sense of a collaborative learning environment a very strong element. This was also a reported outcome of the French TI-Navigator™ with TI-84 research study (Hivon et al. 2008) which also suggested that the TI-Navigator™ had changed the nature of the mathematics classroom environment by:

- offering an opportunity to change the nature of classroom mathematics tasks;
- offering new opportunities for both cooperative and collaborative group learning;
- increasing the complexity of the teacher's role with respect to 'orchestrating' the lesson.

The case study described by Penuel (2008), which used the SimCalc application for the TI-84 with the TI-Navigator™ system also highlighted the importance of paying 'considerable attention to what kind of *tasks* are important to assign students such that the important mathematics is revealed'. Penuel also highlights the importance of the teacher's underlying pedagogical approach, saying 'the power of Alex's pedagogy rests on his ability to exploit connectivity to make visible fundamental concepts of algebra, especially with respect to developing a functional understanding of algebra'. A similar pedagogical approach was evident in lesson reports contributed by Petra, Maria, Jay and Epi during this study.

A comparative research study carried out in Canada (Sinclair 2008), which aimed to contrast aspects of TI-Navigator™ with TI-84 use in three schools reported on the implications of this use on the development of teachers' pedagogical approaches. This study involved 'typical' teachers over the period of a school year and, writing about this progression, the researchers concluded:

They were using student responses as cues for making decisions about the direction of subsequent work, had students working together in pairs or groups, and were beginning to engage students in analysis of errors. We also noticed an increased effort on the part of all four teachers to involve the students in mathematical investigations. (Sinclair 2008, p. 24)

The lessons reported by the teachers involved in this study would indicate that their underlying pedagogic approaches, which incorporate most of the features reported by Sinclair allowed the teachers to capitalise on the features of TI-Navigator™ relatively easily and assimilate them into their classroom practices. Indeed for those teachers for whom TI-Nspire™ was an existing tool in their mathematical toolkit, TI-Navigator™ offered a natural progression towards the collaborative classroom environment that most of them said that they valued.

Sinclair's study also sought to contrast the nature of the mathematical discussions in the experimental (with TI-Navigator) and control classrooms. Whilst also recognising the imbalance between the classroom discussions that the researchers observed, they also concluded that the use of TI-Navigator™ supported the development of richer classroom discourse.

It would seem that in the process of learning the discourse of mathematics, students would benefit from contributing to and talking about shared objects (whether concrete or virtual). Certainly, our observations provide some evidence that, especially in the two classes observed at School B, classroom conversation had started to develop around TI-Navigator displays. Although full discussions were not held, there was a sense in which students were actively and collectively involved in the task at hand. (Sinclair 2008, p. 28)

In common with the findings of this study, Sinclair's research raised the issue of the need for thoughtful lesson planning and considered the implications for teachers in managing the collaborative environment, 'Dealing with a wide range of student responses requires deep knowledge of the subject matter' (Sinclair 2008, p. 34).

6.2 Studies focusing on the use of the TI-Nspire™ handheld

Contrasting the findings of this study with those of the English TI-Nspire™ evaluation research (Clark-Wilson 2008), there are several areas of overlap and some distinct differences. With the insight gained through my role within both studies an obvious conclusion is that TI-Nspire™ tasks designed for use on the handhelds do not necessarily translate to the TI-Nspire™ Navigator™ environment without some adaptation or rethinking. Part of this is due to the fact that, in order to use the TI-Nspire™ Navigator™ environment within a collaborative classroom approach, attentions need to be focused on the same mathematical features or aspects at the same time – which implies a simplification of the TI-Nspire™ pages. Also, despite the facility within TI-Nspire™ to allow multiple applications on a single TI-Nspire™ page, this would not necessarily be visible in the Screen Capture view.

In the TI-Nspire™ Navigator™ study there were more TI-Nspire™ activities which involved dragging (or Grab and move) than in the earlier TI-Nspire™ study. This could be as a result of increased teacher confidence with

respect to their use of TI-Nspire™ but I would hypothesise that it is more likely that the teachers used the Grab and move functionality to provide easy access for students to experience and observe multiple perspectives on the same problem within the shared learning space that TI-Nspire™ Navigator™ offered.

The use of pre-constructed TI-Nspire™ files was relatively low in the English TI-Nspire™ pilot at just 55% of the 61 reported lessons against 80% of the 25 lessons reported in this study. This difference could be explained by a combination of two factors, the increased confidence of the TI-Nspire™ Navigator™ pilot teachers' confidence to construct their own TI-Nspire™ files and ease of file sending with TI-Nspire™ Navigator™. (The English TI-Nspire™ pilot teachers used Connect to Class to send files to the individual handhelds via USB connections from their computer.)

Other recent research relating to the developing classroom use of the TI-Nspire™ handhelds and software has theorised about the issues surrounding the design of tasks and teacher support materials with TI-Nspire™ (Aldon 2008; Arnold 2008; Dick 2008). In considering the design of TI-Nspire™ tasks which incorporate what he calls 'hot links' between multiple representations, Dick describes TI-Nspire as a 'microworld maker' and proposes that, within the design of such microworlds, it is important for both the 'mathematical fidelity' and 'cognitive fidelity' to be maintained. Dick describes these thus:

The former refers to the mathematical faithfulness of a computation or representation (as judged by the math community) while the latter refers to a faithfulness of a machine's representational response to the individual's intended action on the mathematical object being represented. (Dick 2008, p. 6)

There is no doubt that, whilst the content of Dick's paper was speculative, the evidence from the TI-Nspire™ Navigator™ study indicates that the teachers were seeing pedagogical value in designing lessons which focused on particular representations which could be described as microworlds. However, the TI-Nspire™ files within the TI-Nspire™ Navigator™ pilot were of a less complex nature than those described by Dick in his paper, because the teachers perceived that the default visibility of the TI-Nspire™ handheld screens within Screen Capture did not allow for the sharing of text or calculated values. Although the TI-Nspire™ Navigator™ pilot teachers knew that they could enlarge the Screen Capture view, which would overcome this difficulty, the teachers chose not to do this as they considered that the motivating effect of all students being able to see their work on the screen was more important.

Dick hypothesised that, 'even the most compelling hot linked microworld will not deliver results in student learning unless the tasks posed and questions asked by teachers put a premium on sense-making and reasoning' (Dick 2008, p.6). Evidence from this study has suggested that within the TI-Nspire™ Navigator™ environment this important aspect of a teacher's role is crucial in mediating the students' learning. The window into the students' thinking that TI-Nspire™ Navigator™ provides both a support for this, by allowing the teacher to see more deeply than previously whilst also providing a threat to the teacher as they find themselves more exposed in front of the class.

7 Recommendations

The pilot project's aims were to collate evidence about the aspects of the classroom use of TI-Nspire™ Navigator™ that promoted desirable classroom pedagogies and the nature of the rich mathematical starting points that led to enhanced student engagement and achievement in mathematics. This evidence has been reported in Sections 5 and 6 and, as a result, the following recommendations are made with respect to the teachers' professional development needs, the development of exemplar TI-Nspire™ Navigator™ lessons and some possible improvements for the TI-Nspire™ Navigator™ system. The section concludes by suggesting some areas for further research.

7.1 Professional development with TI-Nspire™ Navigator™

The evidence from this study suggests a progression in the way that the teachers engaged with and used the various TI-Nspire™ Navigator™ features. Most began with File transfer, Screen Capture and Live Presenter and, as the project progressed, began to use Quick Poll and embed questions within TI-Nspire™ files to facilitate the use of Class Analysis to review their students' responses. It was clear that cycles of File distribution and redistribution came later in this development journey.

In all cases, the pilot teachers have indicated specific aspects of their TI-Nspire™ Navigator™ use that they would appreciate further professional development to support them to:

- Consider more deeply the nature and content of appropriate Quick Poll questions which could be planned into teaching sequences for use during lessons to support both formative assessment by the teacher and self and peer assessment by pupils.
- Plan sequences of lessons around selected topics, for example Pythagoras' theorem or Quadratic functions which integrate a number of TI-Nspire™ Navigator™ features, as appropriate and also provide bridging activities between the more exploratory introductory tasks and the more traditional text book and examination problems.
- Develop classroom management strategies to deal with multiple, and sometimes unexpected student responses as revealed by the class Screen Capture view.
- Consider the impact of the use of TI-Nspire™ Navigator™ on their students' perceptions of both the nature of mathematical learning in this environment and their expectations of their teacher's role.
- Explore ways of developing teachers' uses of Class Analysis to assist the 'between lessons' formative assessment process and maintain a record of students' responses to tasks and assessments over time.
- Explore ways of using captured Screen shots and Live Presenter videos to support formative assessment processes.

It is strongly recommended that the pilot teachers be supported to continue to meet and disseminate their emerging practices with each other and their colleagues.

7.2 For the development of exemplar TI-Nspire™ Navigator™ lessons

The pilot project has enabled a number of innovative TI-Nspire™ Navigator™ tasks to be developed, several of which could be further elaborated to provide a set of exemplar lessons across a number of mathematics topics. These lessons have been indicated by an asterisk within Appendix 11.7. In particular, it would be desirable to develop some lesson sequences around some chosen mathematical content which exemplify how the various TI-Nspire™ Navigator™ features might be employed at different stages within the teaching sequence. It is the researcher's view that these would need to move from, predominantly exploratory and collaborative starting points towards more individualised activities that would resonate with each country's formal assessments. One of the pilot schools suggested a need for a package of TI-Nspire™ Navigator™ lessons to accompany the traditional mathematics course to exemplify 'best' uses of TI-Nspire™ Navigator™.

The pilot teachers specifically mentioned that they would be keen to develop more TI-Nspire™ Navigator™ lessons which exploited:

- The use of the Screen Capture view to create a 'shared learning space' where the focus was on mathematical generalisations.
- The use of the Screen Capture view within statistical work to visibly increase the sample size and compare results of simulations with a view to drawing students' attentions to the nature of drawing statistical conclusions.

7.3 For TI-Nspire™ Navigator™ product development

As previously stated, this study did not seek to identify technical issues relating to the use of the TI-Nspire™ Navigator™ as these were reported separately to the technical team. However, there were a number of opportunities for the development of TI-Nspire™ Navigator™.

- Within the Screen Capture view in TI-Nspire™ Navigator™ it would be helpful if the screens could be 'unsnapped' to grid so that they could be sorted into groups or placed on top of one another to facilitate mathematical sorting tasks.
- The facility to colour code the borders of the individual students' screens within the Screen Capture view would offer an additional sorting facility.
- Development of the File collection and redistribution facility to recognise when a student had been absent within the cycle and ensure that they are sent the relevant files that had been transferred to their peers' handhelds.
- Review the visibility of various objects and inputs when displayed in the whole class Screen Capture view. This could include some built-in visual resources that support students to show their level of agreement to a particular mathematical conjecture or view.

7.4 For further research

Further research is needed in the following areas to:

- Elicit evidence of the teachers' professional development journey with TI-Nspire™ Navigator™ over a longer timescale with a view to providing evidence of their uses of Class Analysis and File collection and redistribution.
- Explore the classroom experiences of 'average' mathematics teachers who did not necessarily have any experience of using the TI-Nspire™ handhelds or TI-Nspire Teacher Edition™ software.
- Begin to evidence the impact of the use of TI-Nspire™ Navigator™ with students on their perceptions of mathematics, attitudes towards mathematics and ultimately, their mathematical achievements.

7.5 Limitations of the study

A major limitation of this study relates to its short timescale which gave insufficient time for the participating teachers to share their emerging ideas and practices with each other and, as a result, develop a wider repertoire of uses for the different TI-Nspire™ Navigator™ features. Consequently, some teachers did not report any substantial use of Class Analysis or any cycles of TI-Nspire™ file distribution.

Six of the seven pilot teachers could be classed as expert users, having been involved in previous pilot research with handheld technology, in some cases over a number of years. Four of the teachers possess high levels of confidence with TI-Nspire™, enabling them to design sophisticated files and author materials for others. Consequently, although one of the teachers was completely new to both TI-Nspire™ and TI-Nspire™ Navigator™, it is not suggested that the study represents the professional development journey for the wider mathematics teaching population.

The pilot teachers' underlying views and perceptions of mathematics, which influenced both their pedagogic approach and their design of TI-Nspire™ lesson activities, as evidenced by their lesson evaluations, suggested that they were not didactic teachers. All of the teachers adopted a more socially constructivist approach, privileging student exploration and the group generation of the mathematical knowledge. Whilst four different countries' cultures were represented within this study, the close alignment of the teachers' beliefs does not allow any conclusions about 'typical' practice in each country to emerge nor does it allow for the transferability of the research to the more typical pedagogic style within any one country.

8 Table of figures

Figure 2.1 The TI-Nspire™ Navigator™	7
Figure 2.2 TI-Nspire™ Navigator™ software.....	7
Figure 2.3 Sending files.....	8
Figure 2.4 Screen Capture [From lesson BJT2]	8
Figure 2.5 Live Presenter [BJT2].....	9
Figure 2.6 Quick Poll.....	9
Figure 2.7 TI-Nspire Teacher Edition™ software: Question creation for use in Class Analysis	10
Figure 2.8 Example of TI-Nspire™ question [GNH1].....	10
Figure 2.9 Class Analysis view [GNH1].....	10
Figure 2.10 File redistribution.....	11
Figure 4.1 Frequency of use of TI-Nspire™ Navigator™ features (n=25).....	18
Figure 4.2 Using Quick Poll to generate coordinate points that satisfy $x^2+y^2=25$	25

9 Table of Tables

Table 5.1 Overview of the strength of evidence for the different reported uses of TI-Nspire™ Navigator™	36
Table 11.1 The pilot schools.....	46
Table 11.2 Pilot schools' allocations of project resources	48
Table 11.3 Data coding schema	51
Table 11.4 Outline of reported TI-Nspire™ Navigator™ lessons and the supporting data.....	56
Table 11.5 Analysis of TI-Nspire™ Navigator™ lessons by feature used.....	58

10 Glossary

BECTa	British Educational Communications and Technology Agency
CPD	Continuing Professional Development (for teachers)
GCSE	General Certificate in School Education – compulsory examination at the end of Key Stage 4 in England
IB	International Baccalaureate
ICT	Information and Communications Technology
KS3	Key Stage 3 – the phase of education from 11 – 14 years in England
KS4	Key Stage 4 – the phase of education from 14 – 16 years in England
NC	National Curriculum
NCETM	National Centre for the Excellence in Teaching Mathematics
SSAT	Specialist Schools and Academies Trust
STEM	Science, Technology, Engineering and Mathematics
VWO	Vorbereidend Wetenschappelijk Onderwijs or pre-university secondary education in the Netherlands

11 Appendices

11.1 The pilot schools

Code	School	Town, Country	Gender and age range	Pilot class age range	Description of school
B	Blue Coats CE School	Walsall, England	coed 11 – 18	11-15	State comprehensive school
D	Davison CH School for Girls	Worthing, England	girls 12 – 16	12-16	State comprehensive school
G	George Watson's College	Edinburgh, Scotland	coed 11-18	11-16	Fee-paying independent school
Al	Allvar Gullstrandgymnasiet	Lanskrona, Sweden	coed 16-19	15-16	State upper secondary school
Av	Åva Gymnasium	Täby, Sweden	coed 16-19	15-16	State upper secondary school
L	Csg Liudger	Drachten, Netherlands	coed 12-18	16-17	State comprehensive school
S	Sophianum	Gulpen, Netherlands	coed 12-18	16-17	State comprehensive school

Table 11.1 The pilot schools

11.2 Timeline of key project activities

15 th April 2009	Introductory telephone conferences with the teachers and TI personnel from Netherlands.
17 th April 2009	Introductory telephone conferences with the teachers and TI personnel from Sweden.
19 th April 2009	Initial project meeting in London
22 nd May 2009	School visit: George Watson's College, Edinburgh
28 th May 2009	School visit: Csg Liudger, Drachten, Netherlands
29 th May 2009	School visit: Sophianum, Gulpen, Netherlands
2 nd June 2009	School visit: Allvar Gullstrandgymnasiet, Lanskrona, Sweden
3 rd June 2009	School visit: Åva Gymnasium, Täby, Sweden
1 st July 2009	School visit: Blue Coat CE School, Walsall, UK
2 nd July 2009	School visit: Davison CE High School for Girls, Worthing, UK

11.3 Pilot schools' allocations of TI-Nspire™ Navigator™ resources.

Each school allocated the TI-Nspire™ Navigator™ and TI-Nspire™ resources as detailed below.

School	TI-Nspire™ Navigator™ cradles	TI-Nspire™ handhelds
Blue Coats CE School	30	Students were allocated a TI-Nspire™ handheld for use during each lesson.
Davison CH School for Girls	30	Students were allocated a TI-Nspire™ handheld for use during each lesson.
George Watson's College	30	One group of students were allocated a TI-Nspire™ handheld for use during each lesson. A second group were allocated a TI-Nspire™ handheld for both school and home use for the duration of this project.
Allvar Gullstrand Gymnasiet	35	The students had purchased their own TI-Nspire™ handhelds for both school and home in since September 2008.
Åva Gymnasium	30	One group of students had been allocated a TI-Nspire™ handheld for both school and home use since September 2008.
Csg Liudger	30	One group of students had been allocated a TI-Nspire™ handheld and the software for both school and home use since September 2007.
Sophianum	30	One group of students had been allocated a TI-Nspire™ handheld for both school and home use since September 2007.

Table 11.2 Pilot schools' allocations of project resources

11.4 TI-Nspire™ Navigator™ Lesson evaluation proforma

Teaching with TI-Nspire™ Navigator™ – Case study report

The pilot will seek to explain *why* and *how* the interactive classroom works and will be focused on the use of *Screen Capture* and *Quick Poll* in the following ways.

Screen Capture

An exploration of:

- the nature of rich mathematical starting points for which Screen Capture stimulates pupils (and teachers) to learn mathematics;
- the way in which Screen Capture can be used to maximise the opportunities for students' peer communication with (and independent from) the teacher;
- the classroom strategies that the teachers devise to use data from Screen Capture to support them in all aspects of formative assessment.

Quick Poll

An exploration of the types of quick poll tasks which:

- promote formative teacher and peer assessment of mathematics during the lesson;
- collect data for immediate mathematical use by pupils during the lesson activity.

Name:	Date:
School:	Class (and year):
Mathematics level:	Number of students:
During this mathematics lessons I used: (<i>please highlight</i>) File Transfer Screen Capture Quick Poll Class Analysis Other <i>please describe</i>	For the follow up mathematics homework my students used: (<i>please highlight</i>) Only TI-Nspire handheld device Only TI- Nspire software on a PC Handheld and Software TI- Nspire Neither

Describe your planning for the lesson

What mathematics did you want the students to learn?
Describe the TI-Nspire™ Navigator™ activity that you developed.
How did you plan to use TI-Nspire™ Navigator™ during the lesson?
Please list the files (TI-Nspire, Screen Capture, Video) that accompany this lesson.

Now describe what actually happened.

*Please be as detailed as you can – particularly in relation to **when** and **how** you used Screen Capture and/or Quick Poll.*

How did you introduce the activity?
What were students' initial reactions/questions?
Approximately how many of the students could develop strategies to fully pursue the activity with little or no guidance from you?
What, if any, guidance did you have to give to the students? Please indicate how the use of <i>Screen Capture</i> and/or <i>Quick Poll</i> supported you to identify and respond to students' difficulties.
Give examples of the sort of interventions you made, in particular how you used <i>Screen Capture</i> and/or <i>Quick Poll</i> to support these interventions.

Now please evaluate the students' mathematical learning during the activity.

Give a brief summary of the students' work/outcomes in relation to:

Representing mathematics

e.g. identifying the mathematical aspects of the situation or problem; choosing between representations; simplifying the situation or problem in order to represent it mathematically using appropriate variables, symbols, diagrams and models; selecting mathematical information, methods and tools for use.

Analysing mathematics

e.g. making connections within mathematics; using knowledge of related problems; visualising and working with dynamic images; looking for and examining patterns and classifying them;

making and justifying conjectures and generalisations; considering special cases and counter examples; exploring the effects of varying values and looking for invariance; taking account of feedback and learning from mistakes; working logically towards results and solutions, recognising the impact of constraints and assumptions; appreciating that there are a number of different techniques that can be used to analyse a situation; reasoning inductively and deducing results.

Using appropriate mathematical procedures

e.g. making accurate mathematical diagrams, graphs and constructions on paper and on screen; manipulating numbers, algebraic expressions and equations and applying routine algorithms; using accurate notation, including correct syntax when using ICT; recording methods, solutions and conclusions; estimating, approximating and checking results.

Interpreting and evaluating mathematics

e.g. forming convincing arguments based on findings and making general statements;

considering the assumptions made and the appropriateness and accuracy of results and conclusions; being aware of strength of empirical evidence and appreciating the difference between evidence and proof; looking at data to find patterns and exceptions; relating findings to the original context, identifying whether they support or refute conjectures; engaging with someone else's mathematical reasoning in the context of a problem or particular situation; considering whether alternative strategies may have helped or been better.

Communicating and reflecting on mathematics

e.g. communicating findings in a range of forms; engaging in mathematical discussion of results; considering the elegance and efficiency of alternative solutions; looking for equivalence in relation to both the different approaches to the problem and different problems with similar structures; making connections between the current situation and outcomes, and ones they have met before.

In your view, did the use of TI-Nspire™ Navigator™ enhance the students' mathematical learning experience?
If yes, what evidence would you use to support this?

Now please say a little about what you have learned about using TI-Nspire™ Navigator™ from this activity.

Can you comment on how the use of Screen Capture and/or Quick Poll supported you to formatively assess the students' mathematical progress **during** the lesson? Describe any examples of how you used the system and how it changed your actions as a teacher.

What aspect(s) of the idea would you use again?

What changes would you make?

Any other observations...?

pupils' comments...?

other teachers' comments...?

11.5 Data coding schema

The following codes were used to identify the distinct sources of evidence.

Data source	Code	Example
Lesson Evaluation (Teacher)	LEval-T	DCH1(LEval-T)
Lesson Observation	Lobs	DCH1(LObs)
Lesson Structure (i.e. Smart NoteBook or PowerPoint presentation)	LessStr	DCH1(LessStr)
Pre-constructed TI-Nspire™ file prepared by the teacher	tns-T	DCH1(tns-T)
Student's .tns file	tns-S	DCH1(tns-S1) DCH1(tns-S2) etc
Lesson Evaluation (Student)	LEval-S	DCH 1(LEval-S)
Teachers' lesson logs and email correspondences	Log-T	DCH 1(Log-T)
Student interview data	Int-S	DCH 1(Int-S)
Questionnaire responses (Teacher)	Quest-T	DCH (Quest-T)

Table 11.3 Data coding schema

11.6 Teachers' early perceptions of TI-Nspire™ Navigator™

The teachers worked in pairs during the one-day meeting in May 2009 to decide on their 'headline' statements with respect to their understanding (and use) of the TI-Nspire™ Navigator™ system at that time. In several cases at this point in the project the teachers had only used the system once with a class.

Come up with 3 headlines that capture how you think the TI-Nspire™ Navigator™ system enhances students' mathematical learning experience.	HOW YOU KNOW – what is the tangible evidence that you have to support each headline?	Record EXACTLY where the evidence is – i.e. in your lesson evaluation, students' .tns files, or other evidence format.
No more cheating (England)	Students want to see what others are doing to get inspiration by looking at screen capture	My students want to view screen capture with the names on so they can see each other. This promotes students own questions.
Misconceptions are dealt with and much more discussion (England)	Quick Poll set up with questions prepared to (expose and) sort out misconceptions or promote discussion about their maths.	"Sum of two numbers when squared is 25"... 3 and 4 were the most typical responses – what about 4 and 3, 0 and 5, $\sqrt{4}$ and $\sqrt{21}$, etc.
The students are more involved in the lesson (Netherlands)	They can be monitored	
Screen Capture gives a better opportunity to investigate mathematical properties (Netherlands)	Students can get ideas from fellow students	
Quick Poll is anonymous, so more students "dare" to answer questions (Netherlands)	You can only see how many students...but not who...	
Freedom to roam – whilst being watched (Scotland)	Watching what they do that isn't following my planned lesson.	Anecdotes of moments in lessons (see lesson plans)
No written homework (Scotland)	Setting, sending and collecting in electronic homework files.	not done yet (much)
Shy child top of the class (Scotland)	The quietest child chips into the lesson with a though provoking contribution. They normally would remain quiet and unassuming.	
Learning by doing (Sweden)	I think it is easier for the students to understand theorems and connections if they can figure them out themselves.	hittapi.tns randrinkelsatsen.tns
Learning by sharing experiences (Sweden)	They can easily learn from each other when using screen capture and live presenter.	
Learning from discussions (Sweden)	You can easily use Quick Poll to ask questions and then discuss the answers together.	
All students active (Netherlands)	View on all screens	
Every student has an equal voice (Netherlands)	Teacher sees all screens and can give every student a voice (Live Presenter)	
Fast exchange of ideas (Netherlands)	A student can ask to be Live Presenter.	
Get all students involved! (Sweden)	The Screen Capture can show this, the quick poll as well and learning check too.	
Get the discussions in maths going! (Sweden)	Could be recorded and send to the BBC !?	

Come up with 3 headlines that capture how you think the TI-Nspire™ Navigator™ system enhances students' mathematical learning experience.	HOW YOU KNOW – what is the tangible evidence that you have to support each headline?	Record EXACTLY where the evidence is – i.e. in your lesson evaluation, students' .tns files, or other evidence format.
Let the students lead the class!?! (Sweden)	Using Live Presenter could encourage this and hereby make students more confident in maths and Life!	
We all contribute to mathematical learning (England)	Screen Capture allows all students' ideas to become part of the shared mathematical experience.	(Need to be able to record a series of Screen Captures)

11.7 Outline of reported TI-Nspire™ Navigator™ lessons and the supporting data

Brief descriptions of the TI-Navigator lessons reported by the project teachers are summarised below.

Lesson code	Date taught	Lesson title	Brief description	audio recording	teachers' tns file	students tns files	Screen Capture grab	Class Analysis data	Teacher's evaluation	Observation notes	Student feedback
LBW1	Apr-09	Simulating probability 1	Students devised a series of probability distributions based on simulating coin and dice throws.								
LBW2	Apr-09	Simulating probability 2	Students devised a series of probability distributions based on simulating coin and dice throws.								
LBW3	May-09	Test on binomial distributions	Students completed a Test on their own handhelds. Bert monitored their progress using Screen Capture privately on his computer.								
LBW4	May-09	M and Ms*	Students collected and shared data about the weights of packets of M and Ms. Students produced a range of statistical data and graphs.								
LBW5	Jun-09	Hypergeometric distribution	Students used TI-Nspire to define a TI-Nspire function to calculate the hypergeometric function.								
SEvW1	May-09	Multiplication of lines: Intro*	Students explored the effect of multiplying linear functions to produce various parabolas and their properties. Epi invited students to present their emerging theories.								
SEvW2	May-09	Multiplication of lines: Presentations	Students presented the outcomes of their independent research tasks to the rest of the class orally, using Smart Notebook and Live Presenter.								
GNH1	Apr-09	Angle revision*	Students worked within a pre-constructed file which included 3 questions and an exploration. Nevil used Class Analysis to identify key questions to revise.								
GNH2	Apr-09	Standard deviation	Class data experiment - each student 'adding' their data to the class set – in an attempt to justify from the data the $\sqrt{n-1}$ rather than \sqrt{n} part of the formula for StDev								
GNH3	May-09	Minimum triangle*	Students dragged ticks to triangle info to ascertain the minimum info needed for a unique construction. Students checked their answers using paper and pencil techniques.								

Lesson code	Date taught	Lesson title	Brief description	audio recording	teachers' tns file	students tns files	Screen Capture grab	Class Analysis data	Teacher's evaluation	Observation notes	Student feedback
GNH4	Jun-09	Triangle 3*	Students used a series of pre-constructed screens to ascertain which triangles could be drawn given certain sets of info: sas, ssa and sss.								
GNH5	Jun-09	Recurrence relations*	Students explored a dynamic representation of recurrence relations and made notes about their findings.								
GNH6	Jun-09	Vectors*	Students explored a series of dynamic representations of vectors and made notes in response to embedded questions.								
AIPR1	May-09	Proportionality	Students used a pre-constructed file to collect data about the circumferences and radii of circles leading to a linear regression to establish the relationship.								
AIPR2	Jun-09	Understanding functions*	Students used a pre-constructed file to explore the relationship between p and q and the roots of a quadratic given the form $x^2+px+q=0$.								
AIPR3	Jun-09	Lines and points*	Students generated straight line functions through a given point to revise properties of linear functions.								
AvMW1	Apr-09	Circle theorems*	Students used a TI-Nspire file to explore geometric situations involving circles. The file included three Class Analysis questions at the end.								
AvMW2	Apr-09	Exponential fun*	Students explored functions of the form $y=ka^x+c$ leading to discussion about domain, range and asymptotes.								
AvMW3	Jun-09	A cup of tea*	Maria carried out a temperature data capture experiment on her handheld and sent the data to the students for them to try to model exponentially.								
BJT1	Jan-09	Quadratic curves*	From blank G+G page, students varied a in $y=ax^2$ and then c in $y=ax^2+c$ aiming to match a family of curves that the teacher had drawn on the whiteboard.								
BJT2	Jul-09	Exploring Pythagoras*	Students explored varying areas of squares to meet a range of constraints leading to the condition for Pythagoras theorem.								
BJT3	Jul-09	Line symmetry*	Each student contributed a line segment to produce a group symmetry pattern that met a certain set of criteria.								

Lesson code	Date taught	Lesson title	Brief description	audio recording	teachers' tns file	students tns files	Screen Capture grab	Class Analysis data	Teacher's evaluation	Observation notes	Student feedback
DCH1	May-09	Transformation of quadratic functions*	Students created comparative graphs for sets of functions to identify generic transformations.								
DCH2	Apr-09	Circle functions*	Students generated pairs of numbers that summed to give 25 and plotted these as coordinate pairs to explore the resulting graphs.								
DCH3	Jul-09	Exploring Pythagoras*	Students dragged triangles to ascertain that when it was right angled, the two smaller squares' areas summed to give the third.								

Table 11.4 Outline of reported TI-Nspire™ Navigator™ lessons and the supporting data

11.8 Analysis of TI-Nspire™ Navigator™ lessons by feature used

The twenty-five lessons reported by the project teachers are summarised in the table below in chronological order according to when the lessons were taught.

Lesson code	Date taught	Lesson title	Pre constructed file	File transfer	Screen Capture	Quick Poll	Live Presenter	File collection	Class Analysis	File redistribution
LBW1	Apr-09	Simulating probability 1								
LBW2	Apr-09	Simulating probability 2								
LBW3	May-09	Test on binomial distributions								
LBW4	May-09	M and Ms								
LBW5	Jun-09	Hypergeometric distribution								
SEvW1	May-09	Multiplication of lines: Intro								
SEvW2	May-09	Multiplication of lines: Presentations								
GNH1	Apr-09	Angle revision								
GNH2	Apr-09	Standard deviation								
GNH3	May-09	Minimum triangle								
GNH4	Jun-09	Triangle 3								
GNH5	Jun-09	Recurrence relations								
GNH6	Jun-09	Vectors								
AI PR1	May-09	Proportionality								

Lesson code	Date taught	Lesson title	Pre constructed file	File transfer	Screen Capture	Quick Poll	Live Presenter	File collection	Class Analysis	File redistribution
AlPR2	Jun-09	Understanding functions								
AlPR3	Jun-09	Lines and points								
AvMW1	Apr-09	Circle theorems								
AvMW2	Apr-09	Exponential fun								
AvMW3	Jun-09	A cup of tea								
BJT1	Jan-09	Quadratic curves								
BJT2	Jul-09	Exploring Pythagoras								
BJT3	Jul-09	Line symmetry								
DCH1	May-09	Transformations of quadratic functions								
DCH2	Apr-09	Generating circle functions								
DCH3	Jul-09	Exploring Pythagoras								

Table 11.5 Analysis of TI-Nspire™ Navigator™ lessons by feature used

11.9 Summary of students' written feedback [BJT2]

It helped me to see were [sic] everyone else was at

To see others was helpful it showed me other ways people do it, it helps me.

The screen helped me by copying other people's work.

Seeing everyone's work on the board affected my learning by showing the difference between right and wrong diagrams.

I could compare my mistakes and what I done and why compared to others, it helps you improve.

So I could see if i was going wrong.

When I saw everyone's work it helped me improve my work, and see my mistakes

Seeing everyones work on the screen helped us as we could see how to improve our work and it helps if we're stuck.

Seeing everyone's work on the screen helped me to understand more on how to solve the task at hand.

I saw the difference of how the area of squares changed the size of the triangle which helped me to understand the task by seeing it on the screen.

Everyone's work helped because there [sic] was all different.

Could compare my work with others. It showed how my work was better.

I could compare with others.

It shows possible ways of doing my work.

12 References

- Aldon, G. (2008) Report on the work of the French research team e-CoLab ; sharing and constructing resources : presentation of the frame of our work, *Sharing Inspiration* (Berlin 16-16 May 2008).
- Arnold, S. (2008) What are the lessons we have learned from the last twelve months using TI-Nspire with teachers, students, authors and publishers?, *Sharing Inspiration* (Berlin 16-16 May 2008).
- Black, P. & Wiliam, D. (2009) Developing the theory of formative assessment, *Educational Assessment Evaluation and Accountability*, 21(1), pp. 5-31.
- British Educational Communication and Technology Agency (2008) A pupil's entitlement in secondary mathematics, (Coventry, BECTa).
- British Educational Research Association (2004) *Revised ethical guidelines for educational research* (Macclesfield, UK, British Educational Research Association).
- Clark-Jeavons, A. (2005a) *Exciting ICT in maths* (Stafford, Network Educational Press).
- Clark-Jeavons, A. (2005b) Interactive whiteboards: developing a pedagogy for mathematics classrooms in: D. Pimm & S. Johnson-Wilder (Eds) *Teaching secondary mathematics with ICT* (Cambridge, Open University Press), pp. 159-173.
- Clark-Wilson, A. (2008) Evaluating TI-Nspire™ in secondary mathematics classrooms: Research Report, (Chichester, UK, University of Chichester).
- Clark-Wilson, A. (in press) Supporting teachers in introducing new technologies, in: A. Oldknow & C. Knights (Eds) *Enhancing mathematics teaching and learning with digital technologies* (London, Network Continuum).
- Department for Education and Science (2003) Practical Support Pack: Secondary Mathematics, Online at <http://www.dfes.gov.uk/psp/index.aspx> [accessed 09-07-2008].
- Dick, T. (2008) Exploiting next generation handheld technology: TI-Nspire as "Microworld Maker", *Paper presented to Topic Study Group 22 at the International Congress on Mathematics Education 11* (Monterrey, Mexico).
- Dougherty, B. (2005) TI-Navigator™ Technology and Algebra I, (Hawaii, Curriculum Research & Development Group, University of Hawaii).
- Galpin, B. & Graham, A. (2001) *30 Calculator lessons at Key Stage 3* (Corby, A+B Books).
- Glaser, B. & Strauss, A. (1967) *The discovery of grounded theory: Strategies for qualitative research*. (New York, Aldine NY).
- Guin, D. & Trouche, L. (1999) The complex process of converting tools into mathematical instruments: The case of calculators, *International Journal of Computers for Mathematical Learning*, 3(3), pp. 195-227.
- Hiebert, J., Carpenter, T., Fennema, E., Fuson, K., Wearne, D., Murray, H., Olivier, A. & Huma, P. (1997) *Making sense: Teaching and learning mathematics with understanding* (Portsmouth NH, Heinemann).
- Hivon, L., Pean, M. & Trouche, L. (2008) From a network of calculators to collaborative knowledge construction in the class, *Repères-IREM*, 72.
- Penuel, W. (2008) Making the Most of 1:1 Computing in Networked Classrooms, in: J. Voogt & G. Knezek (Eds) *International Handbook of Information Technology in Primary and Secondary Education* (New York, Springer), pp. 943-948.
- Sinclair, M. (2008) TI-Navigator Study Interim Report, (Ontario, Canada, York University).
- Stradling, B., Sims, D. & Jamison, J. (1994) Portable computers pilot evaluation summary, (Coventry,UK, National Council for Educational Technology).
- Teachers TV (2008) *Hard to Teach - Secondary Maths Using ICT*. Available online at: <http://www.teachers.tv/video/29853> (accessed 30th January 2009).
- Texas Instruments (2007a) TI-Nspire™, (Dallas, TX, Texas Instruments Inc).

Texas Instruments (2007b) *TI-Nspire™ Handheld Guidebook Parts 1 and 2* (Dallas, TX, Texas Instruments).

Texas Instruments (2009) *TI-Nspire™ Navigator™*, (Dallas, TX, Texas Instruments Inc).



5. Escriu sobre un dels aspectes
d'importàcia socialitzadora de la
comunicació mitjans electrònica.



Bishop Otter Campus, College Lane, Chichester, West Sussex PO19 6PE UK
Bognor Regis Campus, Upper Bognor Road, Bognor Regis, West Sussex PO21 1HR UK

Tel: 01243 816000

www.chiuni.ac.uk