University of Chichester

Evaluating TI-Nspire™ in secondary mathematics classrooms

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The Mathematics Centre

Research Report

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The project support team was chosen from the existing group of T^3 trainers, an established community funded by Texas Instruments to provide training events and support materials for mathematics teachers implementing handheld technology in their classrooms.

1 Executive summary

1.1 Outline of the project

1.1.1

The revised National Curriculum for secondary mathematics in England and Wales (Department for Children Schools and Families 2007) offers secondary mathematics teachers an opportunity to reconsider their approaches to teaching the curriculum. In addition to the primarily unchanged curriculum content, the new curriculum has an increased emphasis on Key Concepts (Competence; Creativity; Applications and implications of mathematics; Critical understanding;) and the associated Key Processes (Representing; Analysing; Interpreting and evaluating; Communicating and reflecting). There is a strong message to teachers that the curriculum should be taught in a more coherent way by providing students with opportunities to connect mathematical concepts within and between topics. The resource used in this study, TI-Nspire™ (Texas Instruments 2007), offers an ICT based environment which includes a full suite of mathematics software packages that enables mathematics to be experienced through its multiple representations. It was therefore of interest to study the introduction and subsequent use of TI-Nspire™ in classrooms as teachers begun to work within the framework of the new curriculum.

1.1.2

Between September 2007 and April 2008 fourteen[1] secondary mathematics teachers from seven English state secondary schools piloted the use of TI-Nspire™ with learners in classrooms. Six of the schools were piloting the handheld and software, with the remaining school piloting just the software on students' own laptop computers. The teachers participated in seven days of professional development, supported by the project team, which included a group of experts (authors and mentors) who worked alongside the teachers to enable them to become familiar with the new technology, develop classroom tasks, evaluate classroom outcomes and reflect upon the learning processes and outcomes of all involved. The teachers reported sixty-one TI-Nspire™ evaluated lessons to the research team during this period, and these were analysed to reveal trends relating to both the impact of the technology on classroom practices, student learning and the associated teachers' professional journeys.

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[1] One teacher joined the project in December 2007 to replace a teacher who had left that particular pilot school.

The project's aims were to question how TI-Nspire™ might support students to learn mathematics with understanding and to identify the features of an effective professional development experience for teachers learning to use TI-Nspire™ technology in their classrooms.

1.2 Main findings: Learning mathematics with understanding

Learning mathematics with understanding is interpreted alongside the framework developed by Hiebert et al (1997) which describes five dimensions of effective mathematics classrooms in which students are given opportunities to learn mathematics leading to mastery. These highly interrelated features are: the nature of classroom tasks; the role of the teacher; the social culture of the classroom; mathematical tools as learning supports and equity and accessibility. The core features associated with these five dimensions are detailed in Appendix 11.9 of the main report. This framework enables mathematics classrooms to be interpreted with a wide lens and allows for the subtleties of differences between classrooms to be taken into account.

Table 1.7-1 provides more detail on the nature of the evidence that supports each finding, the relevant paragraphs in the main body of the report and indicates the link to the related recommendation(s).

1.2.1

During the pilot, the participating students experienced an increasing number of lessons in which the TI-Nspire™ activities promoted opportunities for them to generalise mathematically. This was a direct result of the more exploratory TI-Nspire™ activities that were being designed for them. The teachers evaluated the use of TI-Nspire™ in these lessons very positively with respect to their students learning outcomes. Where teachers and students evaluated TI-Nspire™ activities highly, there also appeared to have been increased opportunities for students to follow their own lines of mathematical enquiry.

1.2.2

Teachers and students reported that the more exploratory TI-Nspire™ activities resulted in a changed classroom ethos with differences in pace and increased opportunities for collaborative learning. Teachers also reported increased opportunities for students to engage in purposeful plenary activities in which the students shared outcomes and approaches with each other, mediated by the teacher. In a few cases, students were observed offering each other technical support with TI-Nspire™ independent from the teacher.

1.2.3

Where they were given the opportunity, the use of TI-Nspire™ supported the students to develop their confidence and ability to communicate mathematically, enhancing mathematical communication both in reporting their outcomes and in developing their mathematical arguments. Within this context students were supported to develop the correct mathematical terms, vocabulary and syntax to use, prompted by the menus within the software.

1.2.4

Many students benefited from the use of TI-Nspire™ as a neutral tool, providing immediate non-judgemental feedback and promoting incidental opportunities for cognitive conflict.

1.2.5

There were some examples of the students accessing mathematical content that was above the teachers' age-related expectations.

1.3 Main findings: mathematics teachers' professional development with TI-Nspire™

The project has provided rich data from multiple sources about the nature of the professional development experience for teachers in learning to use TI-Nspire™ to use in their classrooms with learners. Table 1.7-2 provides more detail on the nature of the evidence that supports each finding, the relevant paragraphs in the main body of the report and indicates the link to the related recommendation(s).

1.3.1

Initially, teachers selected and designed TI-Nspire™ tasks closely based on their previous experiences, often choosing the most familiar TI-Nspire™ application and seeking to replicate the original task in some way. In some cases the teachers chose a non-ICT task and redesigned it for the TI-Nspire™ environment and in other cases it was adapting tasks developed for other ICT resources.

1.3.2

The collaborative nature of the professional development contributed to the professional journeys of all of those involved. The pace of the professional development was led by the teachers. Where the teachers fully understood the role of their mentor, they were

able to exploit and benefit from this support throughout the project. The project utilised the strengths of the existing T³ (Teachers Teaching with Technology) network of practitioners.

1.3.3

The teachers involved in the project demonstrated high levels of professionalism in the way that they engaged with the process of evaluating their TI-Nspire™ lessons. This was strongly evident in their lesson evaluations in which they were willing to reflect deeply on their existing pedagogy and practice and acknowledge areas for their future development with and without TI-Nspire™ technology. The full range of supporting data collected for each of the sixty one lessons included in this study is provided in Appendix 11.12 of the main report.

1.3.4

By the end of the project all of the teachers had begun to appreciate how the advanced functionality of TI-Nspire™ might influence the design of future tasks and could change the way that they and their students might access some mathematical concepts.

1.4 Implications and recommendations for classroom use of TI-Nspire™

1.4.1

Teachers should select and design TI-Nspire™ activities which offer intriguing mathematical starting points for students and promote exploration leading directly to mathematical generalisation.

1.4.2

Teachers should have clear aims and purposes for the use of TI-Nspire™ that consider both the mathematical and technical prior knowledge of the class such that tasks are initially accessible to learners whilst still providing a clear mathematical challenge.

1.4.3

Where the use of TI-Nspire™ promotes student to follow their own lines of mathematical enquiry, teachers should be prepared to respond to a change of classroom ethos and develop strategies to enable collaborative opportunities for students to share their learning outcomes and communicate their mathematical ideas.

1.5 Implications and recommendations for mathematics teachers' professional development with TI-Nspire™

1.5.1

Professional development involving TI-Nspire™ should include initial activities in which the teachers identify the nature of their existing uses of ICT in their teaching and utilise this to determine their starting points. For example, when beginning to use TI-Nspire™ teachers could begin in the application with which they have most familiarity.

1.5.2

Professional development opportunities involving TI-Nspire™ should include planned opportunities to discuss the meaning of multiple representations within mathematics and how the use of these might support teaching and learning. This could begin with areas of mathematics with which the teachers have most familiarity, such as the links between sequences, functions, tables and graphs within algebra, progressing to the dynamic linking of contexts from geometry and statistics.

1.5.3

Professional development opportunities involving TI-Nspire™ should include a progression of activities and teaching approaches involving the use of dynamically linked multiple representations. These should initially exploit the implicit functionality of TI-Nspire™ and progress to activities and teaching approaches which require the teacher (and/or learners) to explicitly link variables to solve mathematical problems.

1.5.4

Professional development involving TI-Nspire™ should include planned opportunities to explore dragging in a range of mathematical contexts and discuss its pedagogic uses. This should include a consideration of the design of mathematical environments that utilise dragging paying particular attention to "what to drag and why" alongside developing the technical skills and understanding to accomplish this using TI-Nspire™.

1.5.5

Professional development opportunities involving TI-Nspire™ should focus on the collaborative design and evaluation of classroom tasks alongside expert support to ensure progression to the use of the advanced functionality of TI-Nspire™. Where mentor support is provided, a clear contract should be evident, in which both parties fully understand their roles and responsibilities for the benefit of the teacher's professional journey.

Professional development opportunities involving TI-Nspire™ should be structured to allow teachers to engage in cycles of classroom based action research with sufficient time for them to engage in the processes of both oral and written evaluation utilising appropriate robust tools with the support of an expert where required.

1.6 Recommendations for future research

1.6.1

Further research is required to explore how the linking of mathematical variables within TI-Nspire™ applications changes the way that students interpret and communicate mathematics. A particular area of research might examine how students' attentions are drawn to variables and the mathematical knowledge that they gain from such experiences. A parallel or separate study could focus on the teachers' perspective, seeking to identify how teachers make sense of this advanced functionality in order to create tangible classroom tasks.

1.6.2

A further study is needed to research models of school-based professional development involving TI-Nspire™ within whole mathematics departments. This could explore the transferability of the research approach reported in this study to the school setting and help to define further the nature of the resources, including mentor support, required to bring about school-wide implementation of TI-Nspire™ technology within the English school setting.

1.6.3

Whilst this study provided evidence of increased assessment opportunities for both teachers and learners, a more focussed study could explore the nature of this assessment opportunity to include the design of appropriate assessment tasks for different areas of the curriculum and ages of learners. The advent of a wireless classroom solution for TI-Nspire™ provides an opportunity for a systematic longitudinal study to track the mathematical development of selected cohorts of students through their responses to rich exploratory TI-Nspire™ tasks.

1.6.4

This study did not elicit robust evidence about the student ownership model for the TI-Nspire™ within an English schools setting. As the level of teacher expertise with TI-Nspire™ increases it will be possible to research how the student ownership model supports students' mathematical learning. An alternative setting for this study could be

by adopting a more "bottom-up" approach in a less "high stakes" setting, such as with a Year 12 class opting to study a free standing mathematics qualification (FSMQ) which requires students to use technology.

1.6.5

The United Kingdom STEM agenda (Her Majesty's Treasury 2004) is promoting cross curricular approaches to the learning of science, technology, engineering and mathematics in schools. As a comprehensive set of data logging probes for TI-Nspire™ become available, there is an opportunity to research how mathematics teachers can work collaboratively with their science and technology colleagues to promote cross-curricular approaches to solving problems generated from real-life situations.

1.6.6

Finally, an international study, developed to examine how the integration of TI-Nspire™ technology is implemented in different countries, either to contrast approaches to the curriculum or the models for teachers' professional development would significantly contribute to the knowledge base in these areas.

1.7 Summary of the research evidence

Learning mathematics with understanding: Mapping of findings to supporting evidence and recommendations.

Finding	Detailed evidence in main report	Conclusion	Recommendation
1.2.1 During the pilot, the participating students experienced an increasing number of lessons in which the TI-Nspire™ activities promoted opportunities for them to generalise mathematically.	Paragraph 5.2.2 Paragraph 5.2.4 Paragraph 5.2.6 Paragraph 5.2.13 Paragraph 5.2.17 Paragraph 5.2.18 Paragraph 5.2.19 Paragraph 5.2.20 Paragraph 5.3.2 Paragraph 5.3.3 Paragraph 5.3.5 Paragraph 5.3.6 Paragraph 6.3.3 Paragraph 6.3.4	There was strong evidence to support the trajectory of the teachers towards selecting and/or designing more exploratory TI-Nspire™ activities to use in their classrooms. In addition, the teachers evaluated the use of TI-Nspire™ in these lessons very positively with respect to their students learning outcomes. Where teachers and students evaluated TI-Nspire™ activities highly, there appeared to have been increased opportunities for student to follow their own lines of mathematical enquiry.	1.4.1 Teachers should select and design TI-Nspire™ activities which offer intriguing mathematical starting points for students and promote exploration leading directly to mathematical generalisation. 1.4.2 Teachers should have clear aims and purposes for the use of TI-Nspire™ that consider both the mathematical and technical prior knowledge of the class such that tasks are initially accessible to learners whilst still providing a clear mathematical challenge. 1.6.1 Further research is required to explore how the linking of mathematical variables within TI-Nspire™ applications changes the way that students interpret and communicate mathematics.
1.2.2 Teachers and students reported that the more exploratory TI-Nspire™ activities resulted in a changed classroom ethos with differences in pace and increased opportunities for collaborative learning.	Paragraph 5.2.18 Paragraph 5.2.19 Paragraph 5.2.20 Paragraph 5.3.2 Paragraph 5.3.3 Paragraph 5.3.5 Paragraph 5.4.3 Paragraph 5.6.3 Paragraph 5.6.5 Paragraph 6.2.2 Paragraph 6.2.4	The evidence was strong with respect to this finding. Teachers' evaluations, triangulated by student evaluations and mentor observations commented frequently on this. There was good evidence of teachers increased opportunities for students to engage in purposeful plenary activities in which the students shared outcomes and approaches. There was weaker anecdotal evidence to suggest that students were willing to offer each other peer support when overcoming technical difficulties with TI-Nspire™ independent from the teacher, although this was not an aspect that the study sought to probe.	1.4.2 Where the use of TI-Nspire™ promotes student independence of mathematical thought and action teachers should be prepared to respond to a change of classroom ethos and develop strategies to enable collaborative opportunities for students to share their learning outcomes and communicate their mathematical ideas.

Finding	Detailed evidence in main report	Conclusion	Recommendation
1.2.3 Where they were given the opportunity, the use of TI-Nspire™ supported some students to develop their confidence and ability to communicate mathematically, enhancing mathematical communication both in reporting their outcomes and in developing good mathematical arguments.	Paragraph 5.2.8 Paragraph 5.2.9 Paragraph 5.2.16 Paragraph 5.2.18 Paragraph 5.2.19 Paragraph 5.2.20 Paragraph 5.3.6 Paragraph 5.6.4 Paragraph 5.6.5 Paragraph 6.2.2	The evidence for this varies by school context. In some schools the students' outcomes were recorded traditionally on paper whereas in other schools the students recorded their work within TI-Nspire™. In both contexts the evidence was strong to suggest that students were supported to develop the correct mathematical terms and vocabulary to use, prompted by the menus within the software.	1.6.3 Further research is required to explore the nature of this assessment opportunity to include the design of appropriate assessment tasks for different areas of the curriculum and ages of learners. The advent of a wireless classroom solution for TI-Nspire™ provides an opportunity for a systematic longitudinal study to track the mathematical development of selected cohorts of students through their responses to rich exploratory TI-Nspire™ tasks.
1.2.4 Many students benefited from the use of TI-Nspire™ as a neutral tool, providing immediate non-judgemental feedback and promoting incidental opportunities for cognitive conflict.	Paragraph 5.2.7 Paragraph 5.5.5	The nature of the use of TI-Nspire™ within the more exploratory lessons provided strong evidence for the non-judgemental nature of the feedback to students. In addition, whilst the teachers had not explicitly set out to design tasks which promoted opportunities for cognitive conflict, there was good evidence to suggest that the nature of the more exploratory TI-Nspire™ activities often provided this inherently.	
1.2.5 There were some examples of the students accessing mathematical content that was above the teachers' age-related expectations.	Paragraph 5.2.19 Paragraph 6.2.2	Whilst only three teachers commented explicitly on this, in all three cases it was supported by strong evidence from the accompanying students' TI-Nspire™ outcomes.	

Table 1.7-1 Summary of research evidence: Learning mathematics with understanding

Teachers' professional development: Mapping of findings to supporting evidence and recommendations.

Finding	Detailed evidence in main report	Conclusion	Recommendations
1.3.1 Teachers selected and designed TI-Nspire™ tasks closely based on their previous experiences.	Paragraph 5.2.10 Paragraph 5.2.11 Paragraph 5.2.15 Paragraph 5.2.17 Paragraph 5.2.18 Paragraph 5.5.2 Paragraph 5.5.4 Paragraph 6.2.4	This was a strong finding. Although most teachers had some experiences of several ICT tools for mathematics, very few had gone beyond the basic levels of use, which limited their uptake of the advanced functionality of TI-Nspire™ during the lifetime of the project. The study revealed little evidence of the teachers' previous uses of ICT facilitating them to teach mathematics in a connected way. The advanced functionality of TI-Nspire™ (linking of multiple representations) was only beginning to be used towards the end of the project. There was little initial use of the dragging functionality within the early reported lessons.	1.5.1 Professional development involving TI-Nspire™ should include initial activities in which the teachers identify the nature of their existing uses of ICT in their teaching and use this to determine their starting points. 1.5.2 Professional development involving TI-Nspire™ should include planned opportunities to discuss the meaning of multiple representations within mathematics and how this might support teaching and learning. 1.5.4 Professional development opportunities involving TI-Nspire™ should include planned opportunities to explore dragging in a range of mathematical contexts and discuss its pedagogic uses.
1.3.2 The collaborative nature of the professional development contributed to the professional journeys of all of those involved. The pace of the professional development was led by the teachers. Where the teachers understood the role of the mentor fully, they were able to exploit and benefit from this support throughout the project.	Paragraph 5.4.2 Paragraph 5.5.2 Paragraph 5.2.18 Paragraph 6.1.2 Paragraph 6.2.3 Paragraph 6.2.5 Paragraph 6.3.4 Paragraph 6.4.3	There was strong evidence relating to how the collaborative approach to the professional development allowed for the sharing of knowledge and ideas with the teachers learning a lot from each other. The role of the mentors was less well-understood by some schools, resulting in them not utilising this resource fully.	1.5.5 Professional development opportunities involving TI-Nspire™ should focus on the collaborative design and evaluation of classroom tasks alongside a progression to the use of the advanced functionality of TI-Nspire™. Where mentor support is provided, a clear contract should be evident, in which both parties fully understand their roles and responsibilities for the benefit of the teacher's professional journey. 1.6.1 A further study is needed to research models of school-based professional development involving TI-Nspire™ that involves whole mathematics departments.

Finding	Detailed evidence in main report	Conclusion	Recommendations
1.3.3 Teachers fully engaged in the process of evaluating TI-Nspire™ lessons and were willing to reflect on their existing pedagogy and practice, acknowledging areas for their future development with and without TI-Nspire™ technology.	Paragraph 5.2.3 Paragraph 5.2.4 Paragraph 5.3.3 Paragraph 5.3.4 Paragraph 5.4.2 Paragraph 5.5.3 Paragraph 5.6.1 Paragraph 5.6.3 Paragraph 6.2.1 Paragraph 6.2.6 Paragraph 6.3.3 Paragraph 6.5.1	The action research cycles in which the teachers were engaged required an appropriate set of robust evaluation tools. Developing the teacher's use of these tools had a high priority within the professional development sessions. The open and supportive ethos established by the project team supported the teachers to share their ongoing work and identify their areas for development.	1.5.3 Professional development opportunities involving TI-Nspire™ should be structured to allow cycles of action research and sufficient time for teachers to engage in the processes of both oral and written evaluation utilising appropriate robust tools.
1.3.4 By the end of the project the teachers had begun to appreciate how the advanced functionality of TI-Nspire™ might influence the design of future tasks and could change the way that they and their students might access some mathematical concepts.	Paragraphs 5.2.12 to 5.2.20 Paragraph 6.2.2	Although not all of the teachers had progressed to creating their own tasks that exploited the use of dynamically linked multiple representations, there was awareness that this functionality could have pedagogic value.	1.5.6 Professional development opportunities involving TI-Nspire™ should include a progression of activities and teaching approaches involving the use of dynamically linked multiple representations. 1.6.1 Further research is needed that focuses on how the linking of mathematical variables within TI-Nspire™ applications changes the way that students interpret and communicate mathematics. A parallel or separate study could focus on the teachers' perspective, seeking to identify how teachers make sense of this advanced functionality in order to create tangible classroom tasks.

Table 1.7-2 Summary of research evidence: Teachers' professional development

1.8 Additional comments

The study has elicited evidence relating to a number of areas of interest which fall outside of the main research questions but are highly relevant to the adoption and implementation of TI-Nspire™ technology in secondary schools. These are detailed below.

Implementation of TI-Nspire™ in schools

1.8.1

In deciding to implement TI-Nspire™ technology within the mathematics department, schools should be encouraged to consider their wider vision for the introduction of the technology and plan a clear strategy for its introduction. The mathematics department should involve senior managers to evaluate the impact of the use of TI-Nspire™ with students, through focused lesson observations, in a supportive environment. (See Paragraphs 5.4.2 and 6.2.5 in the main body of the report).

1.8.2

If schools are to replicate the process of the teachers involved in this pilot project they would need to plan a programme of professional development, supported by an expert in which teachers have the opportunity to participate in focused collaborative activities. Where the project teachers had dedicated time to meet and work together in their school pairs, often supported by their mentor, they were able to continue to develop tasks and approaches as well as evaluate and refine existing ones. The teachers who did collaborate with each other did so during planning, preparation and assessment time, or through impromptu arrangements. Where the schools had shared department meeting space, the teachers valued this facility and cited it as being instrumental in facilitating collaborative planning. (See Paragraphs 6.4.1 and 6.5.1 in the main body of the report).

1.8.3

The teachers who grasped opportunities to use TI-Nspire™ with many classes became more confident more quickly and, after two terms, were able to continue to develop their own TI-Nspire™ activities and were supporting others involved in the project to do so. It is recommended that teachers embrace opportunities to use TI-Nspire™ in their classrooms to accelerate their personal confidence and competence in the early stages of their development.

1.8.4

Schools should carefully consider the ongoing maintenance and support for the TI-Nspire™ handhelds and software to ensure maximum resource availability for teachers.

This should include the provision of IT technical support to carry out planned software upgrades and battery replacement. (See Paragraphs 6.2.6 and 6.4.2 in the main body of the report)

The TI-Nspire™ Graphs and Geometry application provides significant opportunities for teachers to rethink their own knowledge about geometry, and in particular what drives a geometric construction within a dynamic geometry environment. This could provide a tangible opportunity for teachers to consider when and how variables may be linked to provide opportunities for mathematical generalisation within algebra and geometry.

2 Introduction

2.1 Background to the project

2.1.1

In Autumn 2007, the Qualifications and Curriculum Agency (QCA) introduced a revised National Curriculum for secondary mathematics in England and Wales, for first teaching in Autumn 2008. This curriculum has an enhanced emphasis on the process skills involved in learning mathematics and this context provided an opportunity to research how a multi representational ICT resource such as TI-Nspire™ (Texas Instruments 2007) might enable learners to connect mathematical concepts within and between mathematical topics.

2.1.2

The project adopted an evaluation research methodology to report the impact of the introduction of this new technological tool, TI-Nspire™ into English secondary mathematics classrooms. The research sought "an understanding of the particular circumstances which affect the outcome being examined" (Anderson & Arsenault 2002). However, as the outline structure of TI- Nspire™ presented a new resource for all of the project's participants, the development of the classroom resources and the associated professional development activities contained aspects of a design research methodology (Cobb et al. 2003). Moreover, the participating teachers acted as action researchers (Edwards & Hensien 1999), utilising a range of research instruments to examine closely their own (and colleagues') classrooms, using these to reflect upon their personal professional development as a means to improving their own classroom practice.

2.1.3

The project began in July 2007 and, at that time TI-Nspire™ was not yet available for purchase in England. The evaluation focused on the introduction of the non-CAS (Computer Algebra Software) versions of the handheld and software.

2.2 The research questions

2.2.1

The research sought to evaluate two aspects of the introduction of TI-Nspire™; its impact on learning and teaching in secondary mathematics classrooms (11-16 years) and the outcomes of the professional development experience for the teachers involved in the project.

The principal research questions were:

How does TI-Nspire^{TM} support students to learn mathematics with understanding?

What constitutes an effective professional development experience for teachers learning to use TI-Nspire^{TM} technology in their classrooms?

The nature of the research enquiry led the project's participants to consider each of these questions carefully and deeply as a means of identifying the sort of research evidence that would enable any claims of impact to be substantiated. The professional conversations that ensued were thus inextricably linked to the research process.

2.3 Why this study is important

2.3.1

There has been over twenty years of research into the design and impact of learning technologies within mathematics education and the implications of this for teachers' professional development and their classroom practices (Aldon et al. 2008; Ball et al. 1987; Guin & Trouche 1999; Laborde & Laborde 1995; Noss et al. 1991; Ruthven 1990). A resounding conclusion has been that the integration of technological tools into mathematics classroom practices is a highly complex process which requires teachers to reconsider:

- o their own knowledge and understanding of mathematics;

- o their personal philosophies about the nature of mathematics as a school subject and how it is best taught and learned;

- o their role in the classroom, particularly in relation to managing students' relationships and developing a constructive classroom ethos;

- o their approaches to adopting, adapting and creating tasks which use technological tools;

- o their personal and/or departmental rationale for developing the use of the technology.

2.3.2

The project methodology was research-informed in that it took account of the relevant studies (previous and ongoing) and these in turn influenced the design of the resulting professional development activities.

With the advent of a new technological tool for learning mathematics, TI-Nspire™, which offers a mathematical environment that allows the user to explicitly link variables within a range of mathematical representations, this study offers an insight into the way that English secondary mathematics teachers come to understand this feature and make use of it in their classrooms. In doing so, the new mathematical experiences afforded by the technology offers them a rich setting in which to explore new knowledge and pedagogies for mathematics within the context of their own personal knowledge and that which is applicable to the secondary school mathematics classroom.

3 The research context

As TI-Nspire[TM] is a new software resource for mathematics in England, what follows is a brief description of its structure and functionality and a commentary on the current practices of English secondary mathematics teachers with respect to the use of technology in the classroom.

3.1 A brief description of the TI-Nspire[TM] software

TI-Nspire[TM] includes functionality which was present in previous handheld technology, such as a calculator, function and statistical graphing, lists and spreadsheet and a dynamic geometry application. However, the layout of TI-Nspire[TM] has more in common with the Voyage 200[TM] (Texas Instruments 2002) handheld, utilising a file storage system and a navigation pad (hereafter referred to as the NavPad[2]), rather than the traditional graphing calculator. The individual TI-Nspire[TM] applications will feature in detail throughout the report so what follows is a brief introduction to each one and a description of its basic functionality. These are shown in Figure 3.1-1 to Figure 3.1-7 below. A more detailed technical description of TI-Nspire[TM] can be found in the product manuals. (Texas Instruments 2007a; 2007b)

Home screen

3.1.1

The home screen instructs the user to choose which of the available applications is to be inserted into a new or opened document.

Figure 3.1-1 shows a new Calculator page ready to be added.

Figure 3.1-1 The Home Screen

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[2] Throughout the report the teachers also refer to the NavPad as the Navigational pad and the donut.

Calculator application

Within the Calculator application, it is possible to execute calculations, define and evaluate functions, display and calculate fraction calculations, define variables and evaluate associated expressions (not shown). The calculation sequence shown would be stored automatically when the file is saved.
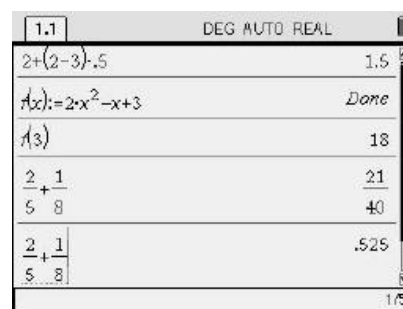
Figure 3.1-2 Calculator screen

Graphs and Geometry application

The Graphs and Geometry application integrates a function graphing environment with a dynamic geometry application. In Figure 3.1-3, a quadratic function has been defined and displayed.

Standard linear and quadratic functions can be transformed by dragging, using the NavPad as well as by editing the function.
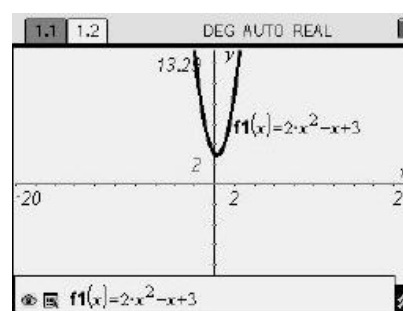
Figure 3.1-3 Graphs and Geometry screen

Graphs and **Geometry** application

In Figure 3.1-4, a Graphs and Geometry page is shown (in plane analytic view with the axes and function entry line hidden) on which a dynamic geometric figure has been constructed and some angle measurements made.

The measurements were defined as variables, which enabled calculations to be carried out on this (and other) pages in the TI-Nspire^{TM} file.
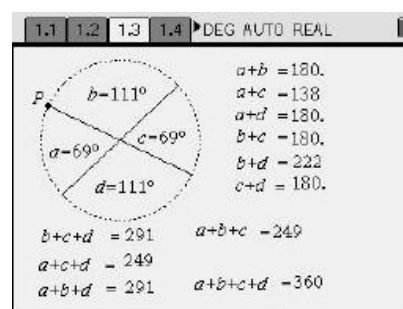
Figure 3.1-4 Graphs and Geometry screen:
[CEL3(tns-S), CHS4(tns-S), PCT3(tns-S)]

Lists and spreadsheet application

3.1.5

Figure 3.1-5 shows an example of a Lists and Spreadsheet page, which follows conventional layout and functionality.

Labelling the columns (not shown) facilitates the construction of statistical graphs based on the data in the columns.

In addition, the cells in the row marked ♦ are used to define functions applicable to the whole column, which includes a data capture facility from dynamic variables (defined elsewhere in the document).

Figure 3.1-5 Spreadsheet screen: [CHS3(tns-S)]

Data and statistics application

3.1.6

A full range of statistical plots and associated statistical calculations can be produced, using variables defined anywhere in the TI-Nspire[TM] file[3].

Statistical graphs can be dynamically explored by dragging individual data points within the data set.
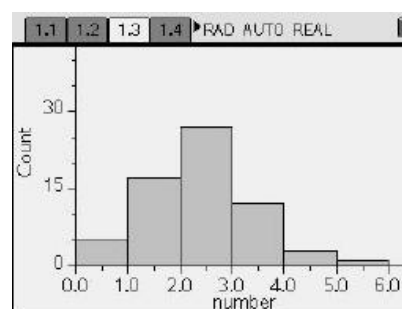
Figure 3.1-6 Statistical plot: [CHS3(tns-S)]

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[3] Variables are actually defined within subsets of the .tns file, called problems, which prevents global definitions from affecting subsequent activities within the tns file.

Notes application

The Notes application supports text input (with basic formatting) as well as the functionality to write mathematical expressions and draw some standard shapes. It also has a comment facility for the teacher or reviewer.
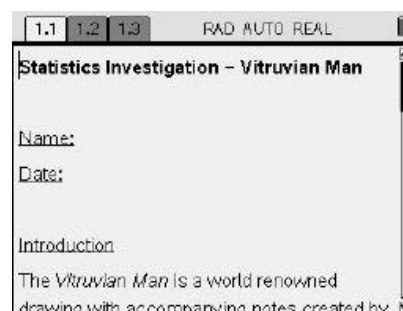
Figure 3.1-7 Notes screen: [GAS2(tns-S), GRE2(tns-S)]

Various combinations of any of these applications can be displayed simultaneously, enabling the user to design the page according their own requirements.

For example, Figure 3.1-8 shows a screen which has been sub-divided to show a Graphs and Geometry page alongside a Notes page.
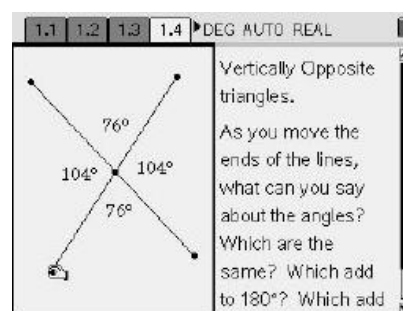
Figure 3.1-8 Split screen layout: [CEL4(tns-S)]

In addition to the separate functionality of the individual applications as described, TI-Nspire™ also includes a directory structure, within which collections of pages (in the form of the applications above) are saved as TI-Nspire™ files (hereafter referred to as .tns files). The ability to provide simultaneously linked multiple representations of the same mathematical model or concept is a significant new feature of mathematical interest to the research study. This multiple representation capability dynamically links graphical curves, axes, equations and tables in simultaneous displays, such that a change in one representation is carried through to the others. In addition, TI-Nspire™ uses a navigational pad to provide a draggable interface, which can be employed to change geometric figures and certain families of functions and statistical plots.

To support the analysis of the TI-Nspire™ activities reported in the study, the facility for linked multiplications is being defined as an implicit linking if it used functionality integral to TI-Nspire™, such as the production of statistical plots from labelled spreadsheet data. Where the user is required to actively define a measured or calculated value as a variable in order to link it to another application, this is described as explicit linking.

3.2 Technology use in mathematics: An overview

3.2.1

The most recent survey of the access and use of technology in English secondary schools was reported by Kitchen et al (2007) on behalf of the British Educational, Communications and Technology Agency (BECTa). The survey[4] was carried out in October 2006 – January 2007 and, as an aspect of the survey was focused on responses made by heads of secondary mathematics departments, some of the findings most relevant to the TI-Nspire™ pilot were:

  o 53% of mathematics teachers were more likely to use subject-specific software in half or more lessons.

  o Online subscription services were most likely to be used by teachers of modern languages (26%) and mathematics (24%).

  o Around 50% of teachers in mathematics used digital learning resources created by others at least once a week

  o 13% of all secondary teachers said they never adapted digital learning resources; however the majority of all secondary teachers (65%) reported that they created their own digital learning resources at least once every two to three weeks.   (Kitchen et al. 2007)

However, what is not evident from the results of this survey is the type of the resources being created or described, or how each resource is being utilised in the mathematics classroom.

3.2.2

There has been explicit reference to the use of technology in secondary mathematics in the English and Welsh National Curriculum (a statutory requirement) since 1995.

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[4] The survey was carried out in a statistically representative sample of secondary schools and it was completed by heads of mathematics, English, science, modern languages, geography and music.

Following the publication of non-statutory guidance on the use of ICT in secondary mathematics in the form of "A pupil's entitlement" (National Council for Educational Technology 1995), the current curriculum, effective from 2000, provided more explicit statements about the use of ICT in mathematics (Department for Education and Employment 1999). For example, at key stage 3,

> *During the key stage, pupils should be taught the knowledge, skills and understanding through: tasks focused on using appropriate ICT [for example, spreadsheets, databases, geometry or graphic packages], using calculators correctly and efficiently, and knowing when it is not appropriate to use a particular form of technology.*

and by key stage 4 (higher), the statutory requirement is,

> *During the key stage, pupils should be taught the knowledge, skills and understanding through: choosing appropriate ICT tools and using these to solve numerical and graphical problems, to represent and manipulate geometrical configurations and to present and analyse data.*

3.2.3

The current school inspection system in England and Wales gives the Office for Standards in Education (Ofsted) the responsibility to evaluate and report whether a school's provision meets the requirements of the National Curriculum. However the extent to which the Ofsted inspection teams are aware of the recent developments with respect to the use of ICT within secondary mathematics may result in a wide ranging interpretation of the quality of the students' experiences. Curriculum guidance documents such as the "Framework for teaching mathematics: Years 7, 8 and 9" (Department for Education and Employment 2001) provide additional exemplification for teachers on the use of ICT for mathematics. The latest report on the use of technology in mathematics from Her Majesty's Inspectors of Schools concluded:

> *The use of ICT to enhance the teaching and learning of mathematics remains too variable between schools; some mathematics departments make use of excellent resources for ICT while others have virtually no access to adequate facilities.* (Office for Standards in Education 2005)

3.3 Technology use in mathematics: A research perspective

3.3.1

Although large scale surveys of the uses of technology in England are carried out by BECTa and within international comparative studies such as TIMMS, these do not probe

the nature of the specific uses by teachers and learners within the school setting. Large scale survey research methodologies are highly problematic due to the many different hardware and software choices within the all-encompassing term technology. For example, one of the questions heads of secondary mathematics were asked to respond to in the most recent BECTa survey was, "How frequently do you use the following resources in lessons?" (Q146) with the possible response categories listed as; Computer packages (e.g. word-processing, spreadsheets); Internet-based resources; Display technologies (e.g. interactive whiteboards); Subject-specific software applications; and Digital video or camera equipment. (Kitchen et al. 2007a). As the categories are not mutually exclusive, a teacher could use dynamic geometric images from an internet based resource on their interactive whiteboard. The survey results can only give a broad picture and, for mathematics, do not really provide much insight.

3.3.2

Smaller, more localised surveys, although revealing, do not give a generalisable picture but provide a snapshot of usage within the locality. For example, a survey of 33 secondary schools in the University of Southampton initial teacher education school network conducted by Hyde (2004) reported the usage of the following ICT resources as: Websites (100%); Spreadsheet (97%); Graphical calculators (94%); CD-ROMS (85%); Word processor (79%); PowerPoint (79%); Data projector (76%); Interactive Geometry software (73%); Graphing package (73%); Logo (73%); and Interactive whiteboard (64%). Again, the major problem with responses to such surveys is the blurring of software and hardware due to the non mutual exclusivity of the categories. For example, which software is being projected by the data projector? And which application within the graphics calculator is being used? In addition, there is no indication of the frequency of use for each of the types of resources. However, what Hyde's survey revealed is the extensive choice the schools had with respect to their access to digital resources, which is a direct result of the significant funding that schools have received over the last seven years from UK government e-Learning investment. (Department for Education and Employment 1997; 1998; 2002). Recent statistics reported that the estimated spend by secondary schools on ICT (excluding curriculum software resources) in 2007 was 281 million UK pounds. (British Educational Suppliers Association 2007).

3.3.3

TI-Nspire[TM] incorporates features of conventional handheld, graphing, spreadsheet and dynamic geometry technology, so a consideration of the recent research with respect to each of these technologies is helpful in framing this project, with an emphasis on naturalistic studies which have examined teachers' practices in the classroom.

Graphic calculators

3.3.4

Graphic calculators have been available in the UK since the early 1990s and, during this time, there have been groups of active users stimulated by a range of projects (Pope 2001; Rodd & Monaghan 2002; Stradling et al. 1994), and teacher networks such as T[3], and subject association journals and resources (National Council for Educational Technology 1996; Pope & Green 1995). However, little is known of the widespread use of graphic calculators in English schools with only a few studies attempting to reveal such data. Of the seven schools involved in a study into practitioner use of technology conducted in 2000 (Ruthven & Hennessy 2002), five reported that the mathematics department had access to a set of graphic calculators. The study reported that, in these five schools, "there was widespread use of graphic calculators – notably for graphing purposes."

3.3.5

A survey of 44 secondary schools in Leeds Local Education Authority (Rodd & Monaghan 2002) revealed that there was little use of graphics calculators at Key Stage 3 (11-16 years), with 6 of the 42 schools reporting usage. At Key Stage 4 no schools reported regular use with students. These results contrast greatly with the later survey conducted by Hyde (2004) of secondary schools in the University of Southampton initial teacher education network, where 31 of the 33 mathematics departments surveyed said that they used graphic calculators. However, in recent years, possibly as a result of the influx of a greater choice of mathematics software and the falling price of computers, there is a general feeling amongst the English mathematics education community that there is less use of handheld technology for mathematics than in previous years. Anecdotal evidence for this is provided by a simple quantitative survey of the number of published articles within teachers' professional journals (Mathematics in School, Micromath and Mathematics Teaching) relating to the uses of graphic calculators in the last three years, when compared to the previous three years. This perceived lack of interest in graphic calculators is not consistent with the research evidence where studies have shown that:

o   graphics calculator technology accelerates the graphing process, allowing students more time to analyse and reflect on relationships between data (Hennessy et al. 2001);

o   the use of the graphics calculator as a shared device can support mathematical learning in the whole class setting (Doerr & Zangor 2000).

A recent systematic review of the use of ICTs in developing pupils' understanding of algebraic ideas (Goulding & Kyriacou 2008) concluded, with respect to the use of graphic calculators,

> *There is evidence that students do not always know how to use the technology, interpret ambiguities in the output and exercise critical judgment when using some of the facilities of advanced calculators. These studies are of relevance to our review question, because they show that the learner has to learn how to use the tool critically before it can be used effectively and also that difficulties in using the tool effectively may be exposing conceptual difficulties.* (p 14)

However, a key recommendation from this report states,

> *Teachers need to help students to make links between symbolic, tabular and graphical output by making these links explicit.* (p 17)

This clearly signals an opportunity for the teachers involved in the project to explore using the linked multiple representations functionality of TI-Nspire™ to this aim.

Dynamic geometry software

3.3.7

Dynamic geometry software has been available for use in schools since the early 1990s. However, as with graphing calculators, its impact on secondary teachers' classroom practices is still relatively unknown. Whilst many schools have purchased the software and there is explicit guidance for its use within key stage 3 curriculum guidance (Department for Education and Employment 2001), anecdotal evidence suggests that there are few schools with planned opportunities for all students to use the software progressively through key stages 3 and 4. It is more likely that one or two teacher enthusiasts provide opportunities for the classes they teach.

3.3.8

In a significant piece of recent research (Ruthven et al. 2004) which focused specifically on the practices of teachers identified as providing "successful practice described by highly-regarded mathematics departments", the researchers explored how these practitioners were using a dynamic geometry system within the teaching of angle-property topics. Ruthven et al observed five lessons across three mathematics topics (angle properties of the circle, angle sums of polygons and corresponding angles) and held post-lesson interviews with each teacher. Their study aimed to "illuminate the didactical thinking informing such use of a dynamic geometry system". Based on their

data Ruthven et al were able to identify themes relating to the teachers' use of dynamic geometry system thus:

- o structuring lessons and mediating student learning;

- o motivating student engagement and agency;

- o working efficiently with dynamic geometry system figures;

- o developing viable approaches to classroom tool use;

- o evidencing geometric properties through dragging figures.

However, in conclusion, Ruthven et al comment that, in their view, all of the teachers within their study were operating within the first classification offered by Laborde (2001a) who described such tasks as "facilitated by" rather than "changed by" the mediation of dynamic geometry system.

3.3.9

Laborde's study involved a team of four French teachers who were developing computer-based teaching scenarios for 15-16 year olds using a dynamic geometry system on a graphical calculator and it is particularly significant as it was the first to offer a theoretical framework to support the examination of teachers' uses of dynamic geometry systems. The teachers involved were designing their own teaching scenarios and, following experimentation in their class, revising them in discussion with other teachers and the researchers. Laborde classified the approaches taken by the four teachers in her study as:

- o the tool facilitates material aspects of task whilst retaining context;

- o the tool facilitates the task by reiterating identified properties;

- o the tool modifies solution strategies, i.e. a more difficult task is made accessible;

- o the task takes its meaning from the tool. (Laborde 2001a).

3.3.10

The TI-Nspire^{TM} pilot will provide a context to examine how the teachers develop their uses of the dynamic geometry application within TI-Nspire^{TM}, whilst offering an opportunity to develop and research new teaching approaches which utilise the linked multiple representations functionality.

Spreadsheets

3.3.11

The opportunity to use Spreadsheets as a source of mathematical enquiry and activity was recognised early on (Ball et al. 1987; Healy & Sutherland 1990) and, for a number of years, many secondary school mathematics departments led the way for the introduction of spreadsheet technology into schools. However, the introduction of ICT as a discrete subject in the National Curriculum (Department for Education and Employment 1995) led the majority of schools to develop an ICT department which oversaw the ICT curriculum. Although some schools delegated the responsibility for the teaching of spreadsheets to the mathematics department, in many cases this became a timetabled part of the curriculum and the focus moved from the application of spreadsheet technology as a tool for mathematical learning to the teaching of generic spreadsheet skills. The current National Curriculum for mathematics (Department for Education and Employment 1999) makes explicit reference to the use of spreadsheets within key stages 3 and 4 with the suggestions that pupils could use a spreadsheet "to generate points and plot graphs", "construct formulae to model situations" and use a spreadsheet to "calculate points and draw graphs to explore the effects of varying m and c in the graph of y=mx+c".

3.3.12

The parallel National Curriculum for ICT contains the more explicit statement:

> *Pupils should be taught to use simulations and explore models in order to answer 'What if … ?' questions, to investigate and evaluate the effect of changing values and to identify patterns and relationships [for example, simulation software, spreadsheet models].* (Department for Education and Skills 1999).

Hence, in many schools the ICT department assumes the responsibility for the introduction of students to spreadsheet software whilst the mathematics departments have a choice about the use of spreadsheets within mathematics lessons.

3.3.13

Mathematics education research into spreadsheets has focused upon developing algebraic generalisations through use of the symbolic language within a spreadsheet environment and supporting the teaching of statistics. In a review of the research with respect to the use of spreadsheets, Jones (2005) concludes that the research suggests that "judicious use of spreadsheets can lead to algebraic understanding". Tabach and Friedlander's recent study of the role of spreadsheet technology in developing students'

understanding of equivalence explored how spreadsheets can be used to mediate "students' acquaintances with syntax, simplifying of expressions or solution of equations", defined by the authors as "transformational" activities (Tabach & Friedlander 2008). This approach is contrasted with spreadsheet activities they describe as "generational" when they focus upon "pattern spotting, descriptions of variation processes, solutions to standard word problems and proportional reasoning". The authors conclude that the design of spreadsheet tasks which provides students with opportunities for learning about symbolic transformations brought about some encouraging benefits such as "emphasising the numerical meaning of equivalent expressions and allowing students to test and validate their solutions". The TI-Nspire™ pilot may provide an opportunity to explore approaches to tasks within the Spreadsheet application which resonate with these research findings.

Previous approaches with multiple representations

3.3.14

The distinctive difference between TI-Nspire™ and other current technologies for mathematics education is the ability to create linked multiple representations between the different applications. Prior to TI-Nspire™, there was an early case study (Evans & Oldknow 1997) which reported the outcomes of a group of 26 Year 12 students (16-17 years) working on the "Sheep pen" maximisation problem using the different applications within the TI-92™ handheld (Texas Instruments 1995).

Evans and Oldknow commented on the different approaches used:

Numeric: *which used lists, functions of lists and the data editor;*

Graphic: *which used functions, tables, graphs, tracing and finding a maximum;*

Geometric: *which used the geometry application for constructions, measuring and dragging;*

Statistic: *generating and exporting data from the geometry applications, plotting scattergrams from the data editor and fitting a regression model;*

Algorithmic: *which used the program editor to create run and edit a program;*

Synoptic: *which used a text editor to write a report.* (Evans & Oldknow 1997)

In this example, groups of students each worked in a different application and then came together during a plenary to share and discuss their own approaches. Evans and Oldknow commented that, although the students found some of the representations easier than others, partly based on their previous experiences, "nearly all found difficulty with the geometric approach: both the mathematical ideas and the technology for realising them were quite new."

3.3.15

Although this functionality has been available to teachers for over ten years, a recent review of the research into the use of technology to support the teaching and learning of algebra in secondary mathematics by Goulding and Kyriacou concluded,

> *Teachers need to make links between functions represented symbolically, in tables and in graphs. Symbolic representations give insights into the structure of functions but require some algebraic fluency to produce. Tables of values, whether produced manually or by technology, are an accessible way into the function idea and give an insight into the effect of inputs on outputs. They emphasise a discrete point-wise view of functions, rather than a continuous idea. Graphs produced by technology give a visual image of a function as an object which can be manipulated in its own right but they also give information about particular points on the functions which is of use in solving equations, and in investigating rates of change.*
>
>   (Goulding & Kyriacou 2008)

3.3.16

It has been possible, with some software packages, to create a dynamic geometry figure and link measurements to a scatter plot and superimpose a mathematical function. An example of this is seen in Figure 3.3-1, which shows the final outcome of a maximisation problem, where the aim is to model the volume of an open tray constructed from a square "piece of card" as the size of the cut-off corners is varied. The point P is a movable object which allows the distance x to be varied. An instantaneous trace of the values of X and the calculated volume is plotted on the graph. Students model the function and use the technology to superimpose it onto the plotted points.
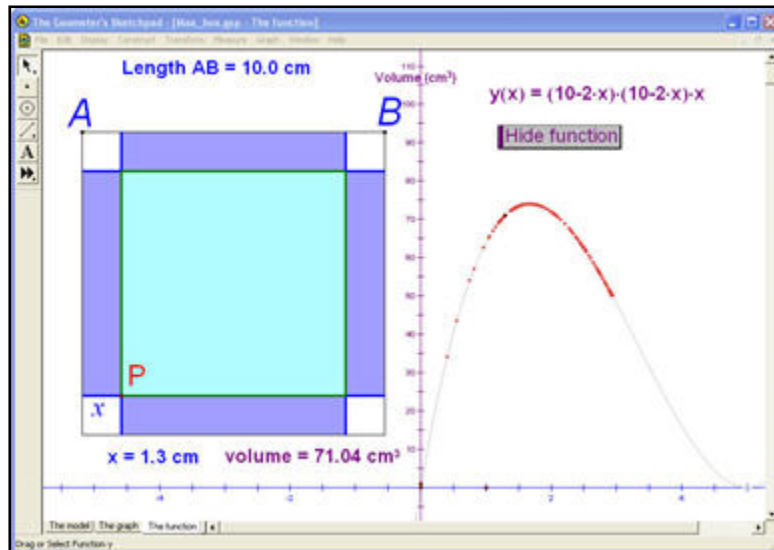
Figure 3.3-1 Example taken from (Department for Education and Science 2003).

Although this example formed part of a government funded professional development project aimed at all secondary mathematics teachers, there is insufficient evaluation data available to evidence how widespread the impact of these resources has been on secondary teachers' uses of ICT.

4 Research methods

4.1 Overview

As the primary research was an evaluation of the impact of the introduction of TI-Nspire[TM] to secondary mathematics, an evaluation matrix (Anderson & Arsenault 2002) was developed, which encompassed the main research questions and considered the forms of evidence that might be sought to support the research process (Appendix 11.1).

4.1.1

Alongside this, the development of the research instruments that would support the evidence to be elicited required the role of the teachers in the research project to be clearly defined, particularly in relation to the way that they would collate and communicate evidence from their own schools and classrooms. This included a consideration of how the teachers would capture their students' own perceptions and views within the research.

4.1.2

The research team was supported by a wider project team which included colleagues with substantial expertise in developing classroom materials and supporting teachers in and away from their classrooms for a range of mathematics technology. Whilst some of the team acted as conduits for the authoring, refining and sharing of lesson materials, others took on the role of a mentor to each school, working alongside the project teachers in school based activities.

4.1.3

There were also members of the technical development team from Texas Instruments present at most meetings, who observed and participated in sessions, providing additional technical support as well as listening carefully to the feedback, some of which is influencing the future developments of the TI-Nspire[TM] software and handheld.

4.2 Selection of schools and teachers

4.2.1

The pilot study involved pairs of teachers from each of seven English secondary schools. The schools were selected such that there was at least one teacher in the school with some experience of using a range of technology in their mathematics classroom. A range of contextual data for each of the schools is provided in Appendices 11.2, 11.4 and 11.5.

Obviously, in agreeing to participate in a pilot project seeking to implement a new technology, the lead project teachers in each school demonstrated a sense of "pioneer militancy" (Artigue 1998) which immediately placed this project in the category of similar studies which sought to research ordinary teachers but, by their nature, only involved extraordinary teachers. In an attempt to lever this position, each lead project teacher was asked to involve a second teacher in their school and, in some cases, the second teacher was asked to participate because they said they lacked confidence with technology. This approach resonates with Ofsted evidence in relation to the development of ICT expertise in secondary mathematics departments.

> *Where a department has at least one member who is a confident and enthusiastic user of ICT, this enables others to share their expertise and take the first steps; before long this becomes self-perpetuating and the department as a whole develops a momentum which benefits all pupils. In contrast, schools with limited facilities or resident expertise need external support, often of a sustained nature, in order for teachers to become effective users of a range of appropriate ICT mathematics applications.*

(Office for Standards in Education 2005)

The teachers ranged in their number of years of teaching experience from 2 to 37 years and described themselves as having a range of confidence and expertise with technology. There was some contrast between the teachers' own descriptions of their current uses of technology alongside the more general overview of ICT use in the schools as described in their most recent OFSTED inspection reports (see Appendix 11.5).

4.3 Organising the students' access to TI-Nspire™

Each of the pilot schools was provided with loan equipment for the duration of the project and each pair of teachers decided for themselves how best to allocate their project resources to students at the beginning of the project (see Appendix 11.6). These decisions were made in relation to the:

- o number of handhelds and/or software licenses available to the project, supplied through the Texas Instruments equipment loan scheme;

- o teaching timetables of the participating teachers;

  o chosen mathematical or pedagogical focus for the teachers.

For example, one school decided to allocate a TI-Nspire™ handheld to each student in two Year 9 classes of roughly similar ability which were taught by the two teachers involved in the project. The school's rationale for this was that the two teachers would be able to plan, teach and evaluate lessons together. Another school installed the TI-Nspire™ software on the laptop computers belonging to all 135 students in their incoming Year 7. Several schools had chosen to focus on using the technology to promote student's paired discussion during mathematical tasks and consequently, divided their allocation between the two teachers accordingly. Initially, all of the teachers chose to work with a focus group of students.

4.3.2

Early decisions about the allocation of the projects' resources within schools had an impact on the progress of both teachers and students in the project, and this will be commented upon in more detail in sections 5 and 6 of this report. As the project progressed, most schools reviewed their early approach and, as teacher confidence and competence with the technology developed, most teachers began to use TI-Nspire™ with wider groups of students.

4.4 The methods of data collection

4.4.1

The project data comprised a range of sources, each of which is described in more detail below. The teachers were given a structured project file in both paper and electronic forms and were encouraged to be systematic about any data they collected, particularly when compiling their TI-Nspire™ lesson components and associated students' outcomes. The teachers adopted a coding system devised by the research team to enable accurate records of lessons to be compiled.

TI-Nspire™ lesson components.

4.4.2

A significant source of evidence for the research was the compilation of the artefacts that constituted the lesson, which will be referred to as the lesson components throughout this report. These differed significantly from school to school and, in the spirit of a naturalistic study, were not defined at the outset of the project. These lesson components were comprised of all or some of the following:

  o a lesson plan, which varied from standard school proforma to hand-written aide-memoirs of the key elements of the lesson;

- o a lesson structure intended for whole-class display, often using software such as PowerPoint or Smart NoteBook (for many teachers these seemed to replace the traditional lesson plan);

- o a pre-constructed TI-Nspire™ file, and in some cases, two different versions of the file, one for whole class display by the teacher and a second for student use on the handheld;

- o student task sheet(s);

- o TI-Nspire™ software help sheet(s);

- o other practical mathematical resources.

4.4.3

The teachers collated these components and submitted them to the research team at the end of the pilot project. In most cases the information was comprehensive enough to enable the research team to understand the lesson activity. Where this was not the case, follow-up conversations via telephone and e-mail took place.

Teacher's evaluations of TI-Nspire™ lessons

4.4.4

The project adapted a lesson evaluation proforma which had evolved through a number of teacher development projects coordinated by the University of Chichester (Ahmed 1987; Ahmed & Williams 1997). The proforma supported teachers to articulate their classroom practices and focus on the identification of the mathematical processes that students engaged in during the lesson. The emphasis during the evaluation process was on supporting teachers to tell the story of their lessons by considering the actions they and the students took – and the subsequent outcomes.

4.4.5

The 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 with respect to the teachers' perceptions of their students' learning and also the teachers' own learning as they critiqued their own practices. The proforma used in the project is included in Appendices 11.7 and 11.8. Part one shows a completed lesson submission for "Angle bisector" [STP3] and Part two shows a completed lesson submission for "Equations of parallel and perpendicular lines" [PSH3].

Mentor's evaluations of TI-Nspire^{TM} lessons

Where the mentor was also present in the lesson they provided formative written feedback to the teacher, which often supported the teacher's own written lesson evaluation. For example, mentors may have canvassed students' views during the lesson or interviewed small groups of students after the lesson, to provide additional evaluatory data.

4.4.7

This feedback also included advice and guidance with respect to the ongoing management of the technology, for example relating to the upgrading of the operating system or developing facilities for the whole class display of .tns files.

Student's evaluations of TI-Nspire^{TM} lessons

4.4.8

The project lesson evaluation proforma included a section which required the teachers to comment on the students' evaluations of TI-Nspire^{TM} lessons. Schools were at liberty to adopt this format into a manageable process for their own context, for example:

o   holding informal evaluation discussions during plenaries and recording relevant student responses in the teacher's (or mentor's) lesson evaluation;

o   presenting students with a written questionnaire;

o   creating online evaluations;

o   including students' comments in the *Notes* application of their .tns files.

Teachers' personal responses to professional development activities

4.4.9

Throughout the project, there were a number of active sessions designed to support the teachers to make best use of the various research tools with which they were to become familiar. For example, the detailed lesson evaluation questionnaire (Appendices 11.7 and 11.8) required in-depth written responses as well as requiring the teachers to seek supporting evidence.

4.4.10

Although the lesson evaluation forms was given out and discussed during the initial meeting, the research team's prior experiences using similar tools led them to plan a 3 hour session at the subsequent meeting to allow the teachers to work in pairs to

complete the process. In reality this meant downloading and reviewing students' TI-Nspire^{TM} files from their class set of handhelds, gathering together the various elements that constituted the lesson and, most importantly, reconstructing the story of the lesson in as much detail as possible. This format was repeated at several of the subsequent meetings in order to give the teachers the time to deeply reflect on the outcomes of the lessons. As part 2 of the lesson evaluation form included the detailed text from the new National Curriculum for mathematics, this presented the teachers with a significant professional development experience as they began to familiarise themselves with the text relating to the key process skills involved in doing mathematics.

4.4.11

Finally, towards the end of the project, the teachers were asked to consider elements of their TI-Nspire^{TM} lessons that they considered to be most desirable and, using a set of statements adapted from Appendix 11.9, they were asked, in school pairs, to prioritise their aims for the future use of TI-Nspire^{TM} in their departments. This task was designed to try to elicit the teachers' own emerging theories for the use of the technology as well as supporting them to consider how they were going to continue to develop activities and approaches, as well as strategies for beginning to involve other colleagues.

Teachers' journal entries

4.4.12

The teachers were encouraged to note down their personal comments and reflections about their experiences throughout the project. These journal entries took the form of personal action plans, comments on significant barriers or catalysts to progress and notes of self congratulation. Such reflections were also evident in the face-to-face, email and telephone correspondences between the project's participants.

Interviews with students

4.4.13

Some informal group interviews were carried out by the Project Researcher with the students who had been allocated their own TI-Nspire^{TM} for both classroom and home use to specifically consider aspects of the individual student ownership model.

Student questionnaire

4.4.14

The project teachers were asked to organise access for all of their students involved in the pilot to an online questionnaire. The question items probed the students' views and perceptions in relation to:

- o the frequency and nature of their use of TI-Nspire™;

- o how using TI-Nspire™ had affected how they engaged with mathematics;

- o evaluating of their overall experiences of using TI-Nspire™.

The design of the questionnaire required some textual inputs (age, NC level etc.); however, the predominant question type required students to indicate their level of agreement to a given statement. However, although 317 students participated in this survey, the results are of limited use as there were only two schools who maintained the same focus group of students throughout.

Teacher questionnaires

4.4.15

The pilot teachers completed an online questionnaire in March/April 2008 which included some questions that mirrored those in the student survey relating to the frequency and nature of their use of TI-Nspire™. Additional questions required them to indicate their level of agreement with a number of statements about:

- o their views of their students' underlying attitudes and motivation to learn mathematics;

- o how they perceived their senior management's response to their involvement in the project;

- o the impact that the use of TI-Nspire™ had on their students' learning;

- o their level of engagement with the TI-Nspire™ project community and their approach to sharing and creating resources;

- o the level of parental engagement with the TI-Nspire™ project;

- o the impact the use of TI-Nspire™ had on their students' motivation and engagement;

- o their future use of TI-Nspire™ in their teaching.

Teacher presentations

4.4.16

A significant data source for the project was the regular, planned opportunities for the teachers to share and discuss their recent school-based work with the whole group during the face to face meetings. These oral reports were always in response to key questions provided by the research team, in advance, to the teachers. At the beginning of the project, they included questions such as:

What would be your "headline statement" regarding your experiences of using TI-Nspire™ with learners to date?

How do you know?

What evidence would you use to support your statement?

At the final presentations, which were audio recorded, the teachers were asked to prepare a presentation that responded to the following questions:

Describe your most successful TI-Nspire lesson to date.

What did "successful" mean to you – within the context of this lesson?

What did you learn?

What did your students learn?

Although the time taken for all fourteen teachers to make presentations was considerable, as their reported TI-Nspire™ use covered a wide range of students (age and ability) and mathematical content, the project team felt that the teachers would gain a significant amount from the processes of presenting and listening to others, in addition to it providing a very rich data source for the research.

Data coding schema

Each school was given a one or two letter code (See Appendix 11.2) 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 submitted (which may not necessarily be chronological).

For example, the first lesson taught by Tim Price of Stadium School is coded STP1.

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

Data source	Code	Example
Lesson Plan	LessPlan	STP1(LessPlan)
Lesson Structure (i.e. Smart NoteBook or PowerPoint presentation)	LessStr	STP1(LessStr)
Pre-constructed .tns file prepared by the teacher	tns-T	STP1(tns-T)
Student's .tns file	tns-S	STP1(tns-S1), STP1(tns-S2) etc
Students' task sheet	Task-S	STP1 (Task-S)
TI-Nspire™ software help sheet	Help	STP1(Help)
Lesson Evaluation (Teacher)	LEval-T	STP1(LEval-T)
Lesson Evaluation (Mentor)	LEval-M	STP1(LEval-M)
Lesson Evaluation (Student)	LEval-S	STP1(LEval-S)
Teachers' ongoing reflections	Refl-T	STP1(Refl-T)
Teachers' presentations	Pres-T	STP1(Pres-T)
Student interview data	Int	STP1(Int-T)
Questionnaire responses (Teacher)	Quest-T	STP(Quest-T)
Questionnaire responses (Students)	Quest-S	STP(Quest-S)

Table 4.4-1 Data coding schema

A complete summary of the data collected for each TI-Nspire™ lesson is provided in Appendix 11.13.

4.5 The role of the project support team

4.5.1

The project support team was chosen from the existing group of T[3] trainers, an established community funded by Texas Instruments to provide training events and support materials for mathematics teachers implementing handheld technology in their classrooms.

The project team had a combined experience which included:

- o   involvement in one of the first pilot projects involving handheld technology in England (Stradling et al. 1994);

- o   authoring classroom activities and resources (Galpin & Graham 1997; 2001)

- o   authoring books for teachers on the use of ICT (Clark-Jeavons 2005; Oldknow & Taylor 2003)

- o   authoring teacher development materials involving both handheld and computer technology for mathematics (Department for Education and Science 2003).

Consequently, the team was able to draw from these experiences, as well as the emerging experiences and findings of the concurrent TI-Nspire[TM] research projects in France, Italy and Germany (Aldon et al. 2008; Arzarello & Robutti 2008; Weigand 2008) to inform their role within the project.

4.5.2

However, as also identified by (Aldon et al. 2008), the project team also experienced the challenges of "developing instrumentation and constructing mathematical activities incorporating TI-Nspire at the same time as learning to use this new tool". Whilst the team drew from activities and approaches used with other technology, it was clear to the project team that the teachers, who did not all have a wide and/or deep experiences of a range of software would not necessarily have this resource to draw upon.

4.5.3

Consequently, the project team decided to support the teachers by:

- o   co-constructing 'bespoke' TI-Nspire[TM] activities for teachers according to the teachers' own specifications;

- o   seeding the project with rich mathematical starting points;

- o   providing individual coaching on the technical aspects of TI-Nspire[TM] to enable the teachers to author their own activities, transfer files to and from the

handheld and make screen grabs to support the production of whole class teaching materials, for example Smart NoteBook files and accompanying students task and help sheets;

o troubleshooting and supporting teachers to debug TI-Nspire™ files that did not behave as planned or expected;

o staying sensitive to the individual teachers' personal confidence in both mathematics and the use of technology.

A subset of the project support team acted as mentors to individual schools for the duration of the project.

4.6 The approach to professional development

4.6.1

In common with other teacher development projects, with and without ICT, there was a clear rationale underpinning the approach the project team took in establishing the ethos and ways of working within the project. (Ahmed 1987; Watson et al. 2003). There was a clear sense of "researching-with", which came about by the privileging of the teachers' classroom stories and by supporting the teachers to substantiate their own claims of changed mathematical performance on the part of their students.

4.6.2

The teachers involved in the project engaged in thirty hours of face to face professional development over seven days the aims of which were to:

o introduce them to the technical features of TI-Nspire™ and develop their personal confidence and competence to use the technology in their classrooms;

o consider how these features might be useful to them in supporting students' learning experiences in their mathematics lessons;

o enable the teachers to design TI-Nspire™ tasks and develop the necessary support materials, for example students' .tns files and task sheets;

o provide opportunities for the teachers to reflect upon the outcomes of their own and their students' classroom experiences with TI-Nspire™ and use a range of research tools to support them to evaluate this;

o enable the teachers to reflect on their own experiences of learning to use and implement TI-Nspire™ technology with a view to considering how they might support other colleagues.

The teachers were encouraged to behave as action researchers by adopting a cyclical approach to evaluating their classroom experiences of using TI-Nspire™ with their learners.

4.7 Ethical considerations

In conducting this research study the ethical guidelines laid down by the British Educational Research Association (2004) were followed. All respondents were guaranteed that their own and their school's names would be anonymised and any interviews were voluntary and confidential.

5 The impact on student learning

5.1 Framework for reporting classroom outcomes

5.1.1

The theoretical framework selected for this study would be used with the teachers to support them to make sense of their own classrooms. Therefore it needed to use terminology that would be readily understood and interpreted by the teachers. It also needed to be broad enough to encompass the complexities of mathematics classrooms. The "five dimensions of the mathematics classroom and their core features", developed as the research outcomes of four separate studies of mathematics lessons in the United States (Hiebert et al. 1997), met these requirements.

5.1.2

These five dimensions are the nature of classroom tasks; the role of the teacher; the social culture of the classroom; mathematical tools as learning supports and equity and accessibility. The core features associated with these five dimensions are detailed in Appendix 11.9.

5.1.3

During the project, sixty-one distinct TI-Nspire^{TM} lessons were reported by the teachers and throughout this report the lessons are referred to by the lesson codes as allocated according to the schema described in paragraphs 4.4.19 and 4.4.20. The complete list of TI-Nspire^{TM} lessons (alphabetical by lesson code) and a brief description of pupil or teacher activity within the lesson is provided in Appendix 11.11. A second analysis of these lessons, detailing the TI-Nspire^{TM} applications utilised within the lesson alongside the contextual data of the class, is provided in Appendix 11.12. A third analysis, which indicates the strength of the supporting data submitted for each lesson, is provided in Appendix 11.13.

5.1.4

The analysis of the data was carried out by scrutinising the lesson components and coding the data in accordance with their degree of resonance with each of the five dimensions.

5.2 Nature of classroom tasks

5.2.1

Hiebert et al describe the core features of the tasks used in the most effective mathematics classrooms as those which problemetise the mathematics, connect strongly with the students' existing knowledge and experiences and, as an outcome, leave "something behind of mathematical value". (Hiebert et al. 1997)

5.2.2

In their lesson evaluations, there were several teachers who commented specifically on the way in which TI-Nspire™ helped them to design tasks which supported students to focus their attention on identifying mathematical relationships and making mathematical connections and also "encouraged exploring, observing and testing conjectures". [LSMF1]. Teachers also commented favourably in relation to the students' retention of mathematics learned during TI-Nspire™ lessons with comments such as "pupils remembered at a later date" [SJK1] and "theories stuck because they'd discovered it" [HAC4]. The lesson scrutiny revealed a high proportion of the later lessons in which this was an underlying feature of the task, although the teacher had not specifically referred to this.

5.2.3

Over the course of the project there were three teachers who commented explicitly on a reduction in their own need to pre-teach the mathematical content in a traditional way or provide extensive task instruction before allowing the students to use TI-Nspire™. This suggests that these teachers were growing in their confidence that the students would learn through their use of the technology without the need for high levels of teacher intervention or over-structured tasks. This was most evident in the sequence of lessons designed by Greenmount School, a school that reports both extensive access to and use of technology within mathematics (see Appendix 11.4) which is supported by its Ofsted report (Appendix 11.5). At the beginning of the project Robert and Amie worked together to design two very structured tasks to enable their Year 9 students to carry out a statistical enquiry using TI-Nspire™, [GAS2], [GRE2] "Vitruvian Man". Amie reported that

> *a lesson had been spent on finding the median, quartiles and interquartile range and using these to draw box plots by hand. This was to ensure that the students could read a box plot and understand what the values actually mean.* [GAS1(T-Eval)].

Towards the end of the project, Amie concluded that her early lessons had adopted "too complicated an approach" [GAS4] and started to experiment with less structured starting points, exemplified by the sequences of lessons she developed to allow students to explore circle theorems "Circles 1 and 2" [GAS5].

5.2.4

In their final project reflections, several teachers said they had fundamentally rethought their approaches to teaching certain aspects of the curriculum. Jeff, whilst reflecting on the lesson [BBJJ7] "Angle bisector", commented on how the "use of TI-N in this context allowed a less algorithmic approach to this topic" and added "even if I wasn't using the software, this would change the way I approached teaching this topic" [BBJJ7(LEval-T).

Another teacher, Sophie, reflecting on her lesson [PSH5] "Enlargements", said,

> "if I had used TI nspire for enlargement when we had [first] covered it, their use of TI nspire would have been quicker and they would have had more time for discovery learning". [PSH5(LEval-T)]

5.2.5

In considering the design of TI-Nspire™ activities, it was useful to carry out an additional analysis of the applications each activity used and how the functionality of the technology was utilised by both teachers and students. (This is detailed more fully in Appendices 11.11 and 11.12). For example, this analysis reveals when teachers chose to use dragging within an application. Analysis of the sixty-one lessons also provided an insight into the design of activities and three categories of use emerged from the project data: single application activities; unlinked multiple application activities; activities utilising the implicit or explicit linked multiple representations functionality. What follows is a description of each category followed by relevant examples, selected because they represent TI-Nspire™ activities which were positively evaluated by the teachers as supporting students' learning.

Single application activities

5.2.6

Just over a quarter of the lessons reported involved the use of a mathematical representation within a single TI-Nspire™ application. For example, in the lesson [STP1] "Prime factorisation" students used the factor command to generate data leading to pattern spotting and generalisation around the nature of the prime factorisation of integers. Tim's reflection on how the technology had supported the student's learning in this lesson concluded,
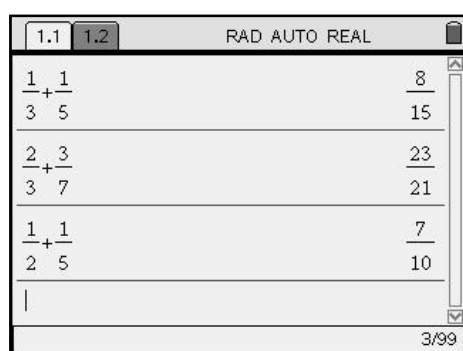
The TI-nspire gave the students the opportunities to attempt to work out how factorisation works, by trying out their own ideas and testing them in a way that would not have been possible in more directed learning, as they could factorise any number that they wanted to and instantly see the prime factorisation, thus giving them further evidence to support or contradict any ideas that they were developing. [STP1(LEval-T)]

5.2.7

Other lessons of this type included explorations of standard form" [HRG1], addition of fractions [HAC4], and the greatest common divisor/lowest common multiple [LSMF4, LSSM3]. In all of these cases, TI-Nspire[TM] was acting as a black box to support student exploration and the technology was often acting as a neutral tool, providing feedback to students to support their enquiry. Inherent in this process, this feedback was challenging students' prior conceptions with respect to the mathematics they were exploring.
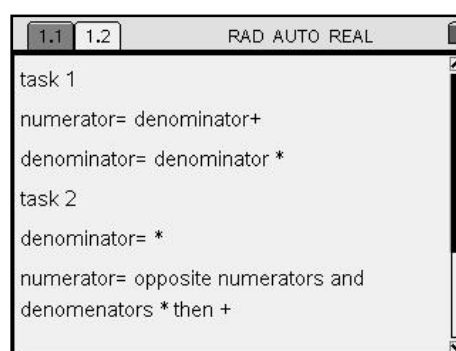
5.2.8

Teachers' lesson evaluations reported an increased emphasis over time on collaborative whole-class learning, with students often making their own lesson notes either on paper, in their exercise books or using TI-Nspire[TM] handhelds or software. Teachers reported that these lessons promoted the correct use of mathematical terminology, convention and syntax, prompted by the technology, which in turn enhanced the students' mathematical communication. For example, in lesson [HAC4] "Fraction addition", the class of Year 8 boys began by exploring the addition of fractions with the same denominator, followed by fractions with co-prime denominators and finally any fractions. In each case, they experimented in the Calculator application and recorded their generalisations using the Notes application.

Figure 5.2-1 Calculation page: [HAC4(tns-S1)]

Figure 5.2-2 Notes page: [HAC4(tns-S1)]
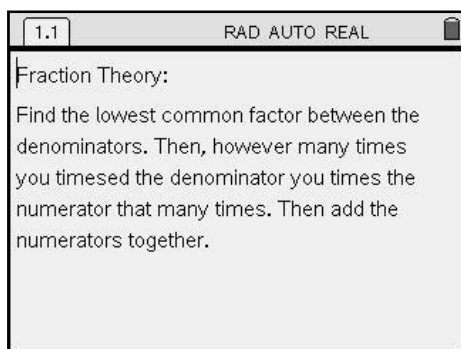
Figure 5.2-3 Notes page: [HAC4(tns-S2)]
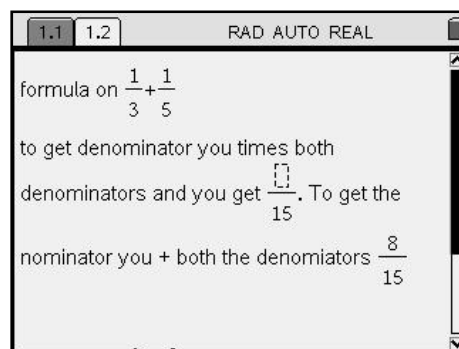
Figure 5.2-4 Notes page: [HAC4(tns-S2)]

One student's evaluation of this lesson stated "I didn't have to get out my book and I still learnt" [HAC4(LEval-S)], indicating the student's appreciation of a different way of learning mathematics.

5.2.9

The keeping of notes attached to particular activities within TI-Nspire™ does raise an issue for teachers and schools with respect to managing the students' access to a particular TI-Nspire™ handheld where the resource is shared within a department. Students owning their own TI-Nspire™ would have a distinct advantage as they would be able to revisit previous tasks for revision, continue tasks begun in school at home and also have the opportunity to transfer their class work on the handheld to their home computer, if they had access to one. This point is corroborated by the students' own responses to the survey question "It would help me to revise mathematics if I could look back on previous activities I have saved on TI-Nspire™", with 43% of respondents agreeing or strongly agreeing with the statement compared with 31% disagreeing and 21% undecided. (n=317) [Quest-S]. For some students they were making this response after a relatively short period of TI-Nspire™ use.

5.2.10

Although the lessons described in paragraphs 5.2.6 to 5.2.8 were favourably evaluated by their respective teachers in terms of both the students' positive attitudes and their mathematical learning outcomes, they did not exploit any of the advanced functionality of TI-Nspire™, such as the ability to link variables between different TI-Nspire™ applications. However they did prove to be valuable classroom experiences for several of the project teachers at an early stage of the project as they were becoming more familiar with TI-Nspire™ and managing its use in the classroom with learners. Moreover, in several of the schools the teachers were not aware of alternative existing technology in their school that would have made these explorations possible. This may appear to be surprising, given the range of technological tools to which the teachers had access (see

Appendix 11.4). However this may be an indication of the limited prior opportunities for professional development in the use of these technologies for some of the teachers.

A second type of lesson, which fell into the category of single TI-Nspire™ application activities, replicated tasks which, in several cases, were already familiar to the teacher from their experience in other software environments [BBAK-JJ1, [CEL1], [CHS2], and [SJK1]. For example, in [PCT2] "Reflecting 2-D shapes", Carla used the Graphs and Geometry application to replicate a task she would have previously used in a dynamic geometry environment. In her evaluation she stated,

> *Their focus was maintained on task throughout the lesson. There was a sense of pride in what they had achieved. The atmosphere was quite competitive regarding their designs. The students were not worried about being seen to be working. The immediate feedback from the activity enabled success and the creativity of the task encouraged students to participate.* [PCT2(LEval-T)]

Whilst Carla did not make any comparison between her experiences of the task in the two different environments, she did comment upon several issues that occurred as she tried to adapt a previously successful task to a new technological tool. These issues related to her lack of familiarity with the syntax for reflecting objects in TI-Nspire™.

Multiple application activities

Approximately three quarters of the lessons reported during the project used multiple applications within the TI-Nspire™ file in varying combinations. Of these, only six lessons used just the Notes page in addition to another application, either to provide task instructions or for students to add their learning notes or responses [LSSM1], [CHS4], [HAC4], [PCT2], [GAS2], and [BBAK-JJ3]. The remaining lessons used varying combinations of applications, some of which were used as separate environments, some that used the advanced functionality within TI-Nspire™ to implicitly link the applications[5]. There were just five lessons that required the teachers and/or learners to explicitly save variables to enable them to be used in another application [LSSM2], [LSMF5], [BBAK-JJ6],[GAS5] and [BBAK8].

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[5] See paragraph 3.1.10 for a more detailed definition of implicitly linked applications.

Multiple applications used separately

5.2.13

A number of the reported activities used each application separately. For example, data collected from a dynamic geometry figure was input manually into a spreadsheet or calculator page [SJK2], [CEL1], [CEL2], and [CHS2]. These lessons fit with Laborde's first classification of use of a dynamic geometry system (see Section 3.3) in which "the tool facilitates material aspects of task whilst retaining context" (Laborde 2001a). However the teachers did evaluate these tasks positively, typified by comments such as,

> *I felt that using the handheld made the lesson far more interesting than having a piece of paper, drawing out triangles, measuring the angles and adding them up. The pupils will remember the 180° more having seen it repeatedly in the totals on the hand held.* [SJK2(LEval-T)]

It is significant to notice that these lessons were devised during the first term of the project, and they tended to use a pre-constructed TI-Nspire™ file, often developed in collaboration with mentors.

5.2.14

When such tasks were presented back by the teachers at the third project meetings, this stimulated the discussion about how the tasks might be developed in a way that exploited the opportunity to link variables, and whether the inclusion of linked variables would be desirable. Some teachers expressed the concern that the more time-consuming approach, whereby students recorded measured data either into the Spreadsheet application or using paper and pencil, might be more advantageous as a learning activity, as opposed to an automated data capture that rapidly produces a table of values. Teachers did not always see the speed at which TI-Nspire™ could carry out such procedures as being beneficial to learners, although none of them tested this hypothesis in the classroom.

Linked multiple representations

5.2.15

The concept of linked multiple representations immediately presented the project team with a mathematical and pedagogical challenge. As only a few of the project teachers had any experience of this concept in other technological environments, there was little existing knowledge with respect to when and why it might be desirable to link variables in different applications and, most importantly, how to accomplish the technical skills required to do this. Beyond this, the teachers had no experience of students working within an ICT environment in which they were explicitly required to do this. By the end

of the project, ten of the thirteen teachers reported that they perceived that the ability to dynamically link different mathematical representations using TI-Nspire™ had supported their teaching and their students' learning [Quest-T].

5.2.16

For the majority of the teachers, the starting point was within the Data and Statistics application, which, by design, requires the user to pre-populate the Spreadsheet and assign the columns of data with variable names. Having done this, moving to the Data and Statistics application prompts the user to select the type of graph and to choose the required variable from a drop down list of assigned variables within the problem. (This is an example of implicit linking of variables). There were a series of lessons devised by the teachers which used this functionality: [GAS1], [CHS3], [SJK5], [LSSM2], [LSMF3], [GAS2], and [GRE2]. Most of these lessons used a pre-constructed TI-Nspire™ file in which the Spreadsheet was already populated with a data set and the columns already defined with variable names. For example, in [GAS1] "Box plots comparison", the students were instructed as to which data sets to compare and the window settings were provided by the teacher. The students were required to select the data set to produce parallel box plots and add their comments on a Notes page.

5.2.17

Judith, in her lesson [SJK5] "Scattergraphs", chose to use a blank .tns file to show her students how to input a given set of data, assign the columns as variables and then plot Scattergraphs to comment upon the nature of any correlation. She concluded that it "was a very effective way to learn about and revise correlation" [SJK5(LEval-T)] and, as her lesson was aimed at preparing her class for their end of key stage 3 tests, she also commented that she would want to develop the approach in the future by allowing students to "collect their own data and use the hand held to draw a scatter graph to see what the correlation is" [SJK5(LEval-T)]].

5.2.18

One of the project team prepared an example of an application of the linked multiple representations functionality which features in the UK version of the First steps with TI-Nspire™ booklet (Texas Instruments 2008). This example was welcomed by the teachers and three of them went on to use the idea, either unchanged or with modification within their classrooms. Annie, who developed the lesson [BBAK8] "Pi Day" for her Year 7 class (11-12 years) using TI-Nspire™ software on their laptops, described the learning objectives for the lesson as:

- *Maths objective: To be able to discover something about pi. Today is "pi day" (3.14) and although circles does not come up in the curriculum until year 8, we are running an event today to publicise it.*

- *TI objective: To be able to use the software independently; To be able to use TI for project based work, using the file format to contain all relevant information* [BBAK8(LEval-T)]

The students opened a blank .tns file and the Graphs and Geometry application (Analytic window). The teacher led them through the construction of a circle and a diameter and demonstrated how to measure the diameter and circumference. These measurements were explicitly defined as variables. They then used the Spreadsheet application to perform a data capture and plot the resulting data as a scatter plot within the Data and Statistics application. Finally, they added a movable line and adjusted its position by dragging until it fitted their data, revealing 3.14 as the gradient. The sequence of screens in Figure 5.2-5 to Figure 5.2-7 show one student's .tns file produced during the one hour lesson.
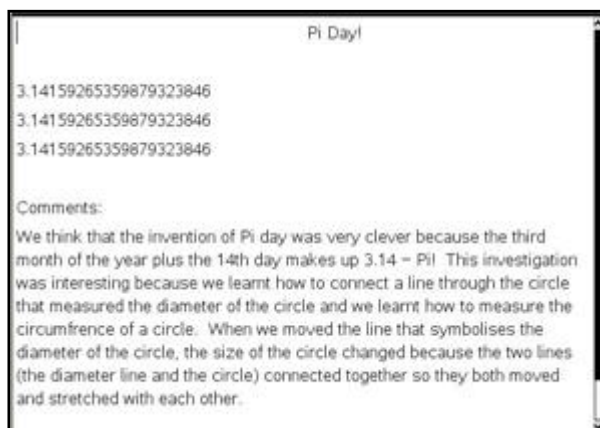
Figure 5.2-5 Notes Page: [BBAK8(tns-S1)]
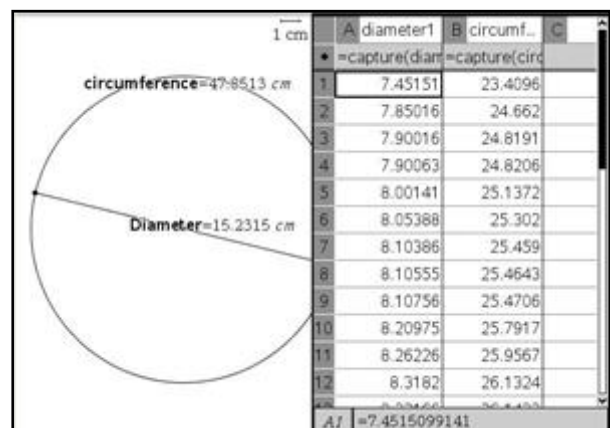
Figure 5.2-6 Geometry and Spreadsheet Page: [BBAK8(tns-S1)]
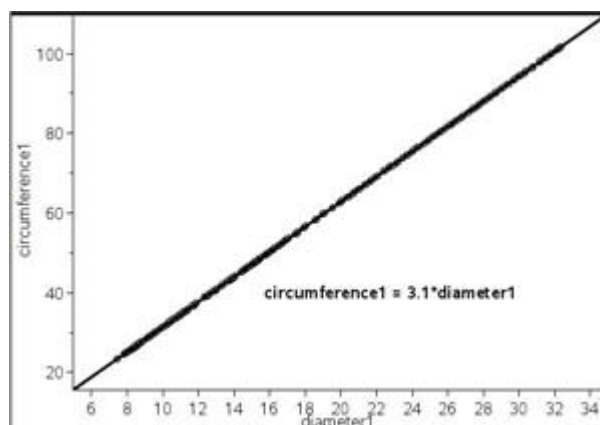
Figure 5.2-7 Data and Statistics Page:
[BBAK8(tns-S1)]

In her lesson evaluation, Annie stated,

> *They drew a segment relatively easily and also a circle, but found it quite difficult to attach the two together so that they were linked. A lot of them did not appreciate the importance of them being linked together until we tried to drag them bigger and smaller and collect the data. It would be good to use alongside measuring real objects. It is a nice idea to plot diameter against circumference and use the moveable line to find the value of pi. We need to change the fix function to get the value to more decimal places – I forgot to do this before the start or tell the kids to do it.* [BBAK8(LEval-T)]

Arzarello and Robutti (2008) refer to this approach as being (in the spirit of Lakatos) a quasi-empirical approach in that it borrows from the sciences in setting up an experimental method to collect data, represent it graphically and explore a mathematical model that fits the data. The teacher reported that the use of the movable line in this scenario enhanced the students' awareness of the algebraic relationship between the diameter and the circumference of a circle.

5.2.19

The lesson "Weighing sweets" [BBAK-JJ6], [GAS-BA3] was developed for TI-Nspire™ following a discussion at a meeting of the T^3 International Assessment Group (T^{3}IAG) in Brussels in November 2007. This Group was exploring rich opportunities for the assessment of students' understanding of the concept of slope and rate of change. The data originated from an experiment in which students, given an opened container of small sweets, were asked to generate their own mathematical questions for exploration and construct an experiment to try to answer their own questions. The resulting experimental data was input to the Spreadsheet application and plotted within the Data and Statistics application. The pairs of teachers in each of the two schools that

developed this activity both chose to carry out an initial lesson where their students were working with a different type of sweet. The teachers then team-taught the follow-up lesson in which both classes shared their learning outcomes, approaches to solving their own problems and how they had used TI-Nspire™. At Bishop Brown School, the teachers used the plenary to display the graphs from the two different classes side by side. This revealed two linear graphs with different gradients, but a common intercept, once scales were made the same. This second lesson at Bishop Brown School was observed by one of the project mentors, who made the following observation,

> Jeff asked for explanations of the difference in the two results and got the "bingo" answer – "is that the weight of one sweet?". He also asked for explanations of why both sets had the same constant – 3.1 – and got "maybe the weight of the cup". Using long names for the lists rather than single letters made the expressions much easier to understand. [BBAK-JJ6(LEval-M)]

Jeff and Annie concluded that during the lesson they were "able to discuss gradients and equations of lines with bright Year 7's – the software allowed us to go further than we might have otherwise". This provides a classroom based example of how the use of TI-Nspire™ with their students had led the teachers to conclude that technology had provided an opportunity for their students to engage with mathematical concepts they would normally have taught later in the curriculum. Other lessons that the teachers concluded were really stretching their students mathematically at Bishop Brown School were [BBAK-JJ3] "Straight line graphs" and [BBAK8] "Pi day".

Referring to the "Weighing sweets" lesson, Amie and Becky at Greenmount School concluded,

> The introduction to straight line graphs from a real life application was engaging and allowed students to focus on a concrete activity. The use of words in the equation of the movable line was very powerful and enabled most students to interpret the equation and how it linked with this particular situation. [GAS-BA3(LEval-T)]

5.2.20

Finally, a series of lessons devised towards the end of the project by Amie, [GAS5] "Circles 1 and 2" exemplified how one teacher was able to explicitly link variables to provide a rich exploratory task for her students to explore circle theorem. Amie's objective in the first lesson was "I wanted them to discover two circle theorems – opposite angles in a cyclic quadrilateral make 180 and angles in the same segment are equal" [GAS5]. Amie described how she introduced the lesson thus:

I had my TI-nspire and the software on my IWB and I guided the students through the process of creating the split page and generating the circle and cyclic quad before allowing them to explore what happened to the angle sums… … I got them to measure each of the angles within the cyclic quadrilateral and store them as variables. This enabled them to move the quadrilateral and/or the circle around and see what happened to the angles. I asked them to calculate various sums each time they had adjusted the diagram and then note down what they noticed. [GAS5(LEval-T)]

Figure 5.2-8 and Figure 5.2-9 each show an example of two different students' final .tns files from this lesson.
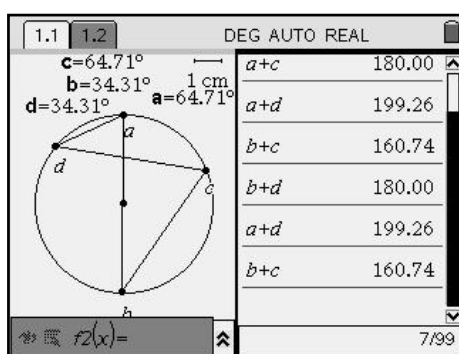
Figure 5.2-8 [GAS5(tns-S1)]   Figure 5.2-9 [GAS5(tns-S2)]
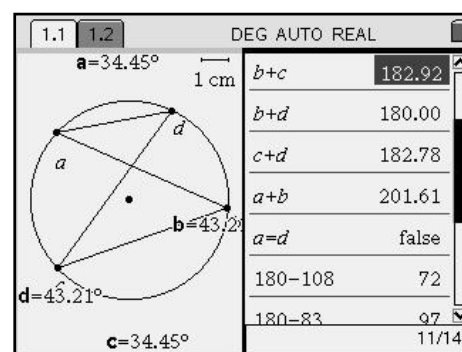
In both cases the students had progressed from the initial task, in which they explored angle sums for the different pairs of interior angles, to dragging the position of one or more vertices. This led to the scenario where they could draw conclusions about the size of the angles on the same segment. In Figure 5.2-9, the student appears to have arrived at a new meaning for the equals sign in that it is being used, not as a symbol to evaluate an answer, but to test the validity of a statement. However, it is not known whether the student typed this deliberately or accidentally, or how they resolved the resulting display. The same student also chose to check his or her conjectures by resorting to numerical calculations, rather than using the named algebraic variables, which could signify a lack of confidence to work in the algebraic domain. In her lesson evaluation, Amie concluded,

I feel that they are stronger at applying these theorems as they have been able to discover them for themselves and play about with the circle and cyclic quad as much as they liked and still see that they hold… … I feel that my teaching of this topic has been enhanced by this activity. Although it could have been done on a geometry program in a computer room, the use of the TI-nspire was less disruptive and as this class have used them before it was easier for them to access. I feel that the pupils will remember these circle

theorems as they have had a practical lesson to discover them rather than being shown or told them and then simply applying them. [GAS5(LEval-T)]

Students from Amie's class were interviewed in small groups about their overall experiences of using the TI-Nspire™ handhelds during the project [GAS5(Int-S)]. A group of five girls agreed that using the TI-Nspire™ had helped them to learn and cited the example of the circle theorem lessons, saying that it was beneficial to generate lots of different examples quickly. They appreciated that there was an investment in learning to use the technology and overcoming any technical difficulties to enable them to use TI-Nspire™ for learning new mathematics. Another group of three corroborated that "educationally, circles was the most effective", with one student saying that she was learning most from the circles project.

5.3 The role of the teacher

5.3.1

In effective mathematics classrooms, (Hiebert et al. 1997) define the core features of the teacher's role to select the classroom tasks with clear aims and objectives in mind, share the essential information with students to enable them to be successful and be responsible for the establishment of a positive classroom learning culture.

5.3.2

All of the project teachers prioritised the need to select tasks with clear aims in mind, as was most evident from their lesson plans and evaluations. At the beginning of the project these aims tended to focus on traditional mathematical aims for the lesson, for example, "Vertically opposite angles are equal" [CEL3(LEval-T)] and aims related to learning specific technical skills with TI-Nspire™ such as "How to generate sequences using ICT and interpret their results" [PSH1(LEval-T)]]. As the project progressed, all of the teachers professed in their final presentations that the nature of their planned lessons had shifted to offer the students a more exploratory learning experience with a change in the mathematical focus. For example, the mathematical aims for the [LSMF3] "Trial and Improvement" lesson were for students to "see the relationship between values generated for the function and the shape of the graph of the function" [LSMF3(LEval-T)] and in the activity [BBAK-JJ3] "Investigating straight lines", Annie and Jeff stated "For the first time we did not prepare a TI file at all and got the students to open a blank file and decide for themselves how to set the file up" [BBAK-JJ3(LEval-T)].

5.3.3

Towards the end of the project nearly all of the teachers were seeing the value of including specific learning objectives which related to developing the students technical

fluency with TI-Nspire™, as evidenced by their lesson plans and evaluations. The teachers showed a much greater awareness of their students' previous experiences with TI-Nspire™ and the progression in students' TI-Nspire™ technical skills. The teachers were also becoming more confident at choosing when to and when not to use the technology, with many stating that their ideal was for their students to have enough technical fluency to be able to make this choice for themselves. Student evaluations offer some triangulation for these changes in emphasis, for example "Sir does not give us an answer straight away" [STP1(LEval-S1)]. and "We were not told the strategy" [STP1(LEval-S2)].]. As a result of this shift in the lesson design, the teachers also reported a change in the way that they organised the lessons, with one teacher stating that she now saw "a need for a meaningful plenary" [CEL3(LEval-T)].

In the lesson [SJK4] "Straight line graphs", Judith had wanted her students to adopt an exploratory approach and find out,

> *What effect changing the 'm' has on the straight line, keeping 'c' constant and what effect changing the 'c' has on the straight line, keeping the 'm' constant. Trying to get from them what the 'm' is and what the 'c' is.* [SJK4(LEval-T)]

and in her evaluation of the lesson outcomes she commented specifically on her changing role thus:

> *It was very difficult to get a generalisation from the pupils. I feel perhaps it was the way I questioned them. When looking at the 'fan' going through the point (0,5) there was little that the students spotted apart from the fact that it looked like a fan! Perhaps they were more concerned with the 'm' changing than the 'c' remaining constant. I shall try to put more thought into my questioning in future!* [SJK4(LEval-T)]

Judith's comment provides an example of how the technology had provided a rich context for mathematical learning and yet the technological output resulted in conflicting interpretations. The students saw a fan, whilst Judith wanted them to generalise about the family of all straight line equations of the form $y = mx + c$ with the same value for the constant, c. Her comment, however, suggests that she had learned from the classroom experience and would be better prepared to respond to similar student conclusions in future similar lessons.

5.3.4

Mathematics lessons involving ICT will inevitably involve some level of instruction with respect to the technological tool and it is very firmly within the teacher's role to mediate this process. The teachers chose to do this in different ways, with some using whole class display (TI-Nspire™ ViewScreen with an overhead projector or displaying the TI-

Nspire^{TM} software through a data projector), whilst others developed detailed student instructions. In several cases the instructions led the students through the task. Andrea, in the lesson, [HAC2] "Temperature conversions", developed a "step-by-step worksheet to take the boys through the stages required to achieve the desired outcome" [HAC2(LEval-T)] and subsequently concluded that "due to the fact that they are a very intelligent class I feel that I underestimated their ability and maybe should have made it more challenging mathematically for them" [HAC2(LEval-T)]. Her students were quick to learn to input data into the Spreadsheet, produce a scatter plot within the Graphs and Geometry application and input a given function to produce the conversion graph. Andrea appreciated that the task lacked mathematical purpose, in that the students were not asked to use or interpret the resulting graph to solve any further mathematical problems.

5.3.5

There were a few occasions when the teachers chose to centrally involve the students in supporting each other to troubleshoot the technical difficulties they encountered. Eleanor spoke positively of the students in her class moving to form "huddles" [CEL5(LEval-T)] around their handhelds, sharing approaches and overcoming difficulties, whereas at Bishop Brown School, Jeff and Annie used the opportunity of their team-taught lesson for the students in one class to teach the students from the second class how to produce a scattergraph and add a movable line [BBAK-JJ6]. Both of these examples strongly suggest a particular classroom ethos in which the students' own contributions are highly valued by their teachers and the teachers are flexible in the way they use their learning space, trusting them to make sensible choices to enable them to achieve the desired mathematical outcomes. In both cases, this is made much more possible by the portability of the handhelds (or laptops), offering a distinct advantage over a fixed computer suite arrangement.

5.3.6

A key aspect of the nature of TI-Nspire^{TM} classroom tasks is concerned with their design. Ainley, Pratt and Hansen (2006) identify the following paradox concerned with pedagogic task design in that,

> *If teachers plan from tightly focused learning objectives, the tasks they set are likely to be unrewarding for the pupils, and mathematically impoverished. If teaching is planned around engaging tasks the pupils' activity may be far richer, but it is likely to be less focused and learning may be difficult to assess.* (Ainley et al. 2006)

This was certainly evident within this project as teachers moved towards more rewarding uses of TI-Nspire™, they were then faced with the task of trying to find opportunities to maintain the mathematical focus in relation to the curriculum. However there was convincing evidence that, as the teacher's familiarity with the affordances of TI-Nspire as a mathematical tool improved, they became more confident to allow the students to determine their own mathematical path. By placing more emphasis on students' peer and self-assessment, often utilising the Notes facility within TI-Nspire, the teachers developed strategies that meant they were more confident that learning was taking place and were able to evidence this.

5.4 Social culture of the classroom

5.4.1

Hiebert et al (1997) define the social culture of an effective mathematics classroom as being one where, within the classroom, the students' ideas and methods are valued, the students are encouraged to choose and share their approaches and, where mistakes surfaced, they become new opportunities for mathematical learning. Finally, the rigour and correctness of mathematics lies within the mathematical arguments that students put forward, with the teacher encouraging them to participate actively in such discussions.

5.4.2

The teachers' own views and beliefs about mathematics, and how it should be taught and learned, are evidenced through the ethos they establish in their classrooms. One of the professional development activities was designed to support the teachers to consider, in school pairs, their priorities for ways of using TI-Nspire™ in their classrooms as a means to explicitly considering the classroom culture that this would engender. The teachers were asked to discuss a set of statements that had emerged from the project as being important when making decisions about the use of TI-Nspire™ in their classrooms (Appendix 11.14). In response to this task, whereas Coastway school prioritised students choosing when or when not to use the technology and the technology being used to stimulate students' discussion about mathematics, Stadium School thought it important that TI-Nspire™ would enable the students to try and test their own ideas. Lime Street School was initially alone in the project in that, from the outset, the teachers were very committed to the students being involved in the construction of the TI-Nspire activities for themselves. They used few pre-constructed files, but this did not serve as a barrier to them developing tasks which linked variables. An example of this was the lesson "Trial and improvement" [LSSM2] and [LSMF3], which adopted an innovative approach to introducing a graphical dimension to what was

usually a purely numerical strategy. Their project mentor played a significant role in devising activities which developed the teacher's confidence to use the more advanced features by producing detailed task instructions (see Appendix 11.15).

5.4.3

The teachers' lesson evaluations included many comments relating to their observations of a change in the classroom ethos which promoted students to take more responsibility for their mathematical learning. For example, when describing her lesson "Triangles" [CHS2], Helena wrote:

> *It opened up a forum so that they were probably more willing to discuss what they were seeing and doing with each other and with me. It threw up questions for the more astute in relation to the rounding of the angles not giving the total that was expected.* [CHS2 (LEval-T)]

The students themselves commented on the classroom culture within TI-Nspire™ lessons, with feedback such as "we got to discuss with other people" [BBAK1(LEval-S1)] and "we could experiment without being told off" [CHS1(LEval-S2)].

5.4.4

The lesson [STP3] "Angle bisectors", designed by Tim, deliberately misconstructed a geometric figure to draw his students' attentions to the core features of a successful geometric construction that would result in an angle bisector. A static image of the .tns file is provided in Figure 5.4-1. The teacher and students adjusted the sizes of the circle to ascertain when the angle would be bisected. Tim commented that an important aspect of the lesson outcome was,

> *Rather than being given a set of instructions to follow, students made sense of a moving diagram in which the angle bisector exists as a special case. Students were able to understand what it is about the construction that makes it work.* [STP3(LEval-T)]
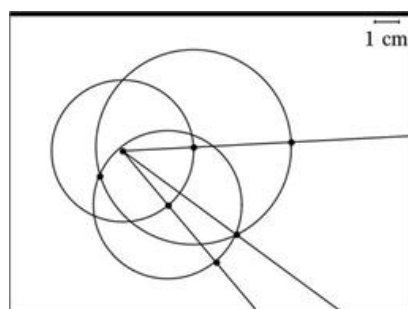
Figure 5.4-1 Geometry page [STP3(tns-T)]

The task developed such that the students then used paper, pencil and compass construction techniques to consolidate their understanding before moving on to design

an angle construction fan, which required students to use TI-Nspire™ to successively bisect the angles to produce an intriguing image which, when dragged, would open and close whilst still retaining the bisected angles. Although Tim had not used exactly this approach previously, his existing skills with dynamic geometry software enabled him to confidently construct the task for the handheld. (The detailed lesson evaluation for this activity is included in Appendix 11.7.)

5.5 Mathematical tools as learning support

5.5.1

Hiebert et al's (1997) interpretation of the term *mathematical tools* is broad in that it includes students' existing mathematical schema (mental images and learned strategies) in addition to the physical tools and structures provided by the teacher. The research carried out by Hiebert et al did not focus on the use of technological tools as learning supports. However there is a degree of resonance between their conclusion that "the meaning for tools must be constructed by each user" and Guin and Trouche's concepts of instrumentation and instrumentalisation (Guin & Trouche 1999).

5.5.2

The teachers' initial reactions to the TI-Nspire™ handheld were influenced by their previous uses of technology. With an initial choice of four[6] different starting points (Calculator, Graphs and Geometry, Spreadsheet and Notes), the teachers' attentions tended to go towards a more familiar application at first. The teachers from Coastway school, who both had experience with dynamic geometry software, started in the Graphs and Geometry application (Analytic window), whilst the teachers at Lime Street School began in the Calculator application. In the early professional development sessions, the project mentors' roles were crucial in supporting the teachers to gain familiarity with each application, whilst considering how the functionality might be utilised to develop classroom tasks. It was important that each project mentor listened carefully to the teachers' own questions and supported them to both explore the functionality, whilst offering suggestions as to teaching and learning opportunities that were emerging. In these early sessions, the complexities of the tool meant that some of the teachers immediately saw a need to introduce their students to some basic file management skills and the ability to move between pages in TI-Nspire™ files.

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[6] The Data and Statistics functionality was not available at the outset of the project.

As already mentioned in Section 5.2 within the context of students' prior mathematical knowledge, some teachers held the preconception that they would need to pre-teach the technical skills before they could go on to focus students' attentions on the mathematics. For example, in her evaluation of the lesson [PSH1] "A Rich Aunt", Sophie commented that "the pupils may have progressed further in the activity if a lesson on formulae in Excel has been taught previously" [PSH1(LEval-T)]. A similar comment was made by Amie during the lesson "Vitruvian Man" [GAS2], who said,

> *Once the class had begun trying to analyse their data there were a few problems. Some pupils found it difficult to use the sort function to put their data in a particular order. I found this surprising as I expected them to have knowledge of spreadsheets on a PC and so realise the need to highlight all columns before sorting.* [GAS2(LEval-T)]

Similar teacher comments also related to how their students overcame specific technical aspects of using the TI-Nspire™ handhelds, in particular, using the NavPad to drag objects. Commenting on the series of lessons, "Angles" [PCT3], Carla wrote:

> *by the third lesson most pupils could navigate (the TI-Nspire™ file) and use the donut more effectively.* [PCT3(LEval-T]

In general, those teachers who developed lessons which used the drag functionality expressed surprise at how quickly their students mastered the technique.

5.5.4

Not all of the teachers chose to involve dragging in their lessons. Of the sixty-one lessons, twenty-one lessons (taught by nine different teachers) involved the use of the grab hand to select a mathematical object (point, geometric line or movable line) to drag it to a new position and observe the outcomes. Appendix 11.12 identifies these lessons and, as this table is arranged chronologically by lesson, there was an observable trend that the use of dragging increased through the period of the project.

5.5.5

There was one particular lesson, which provides a rich example of how the functionality that TI-Nspire™ affords, allowed a teacher to consider approaching a mathematical topic in a completely new way (for her). In the lesson, [PSH3] "Equations of parallel and perpendicular lines", Sophie started with a blank Graphs and Geometry page and asked her students to generate a linear function from its equation. Based on their prior knowledge of linear equations, she then asked them to generate a second line which crossed the y-axis at the same point. They then measured the angle between the two

lines (defined by the points where each line crossed the x-axis and their intersection point) and then rotated the second line (by dragging) until the achieved an angle of 90°. An example of this is shown in Figure 5.5-1 and Figure 5.5-2.
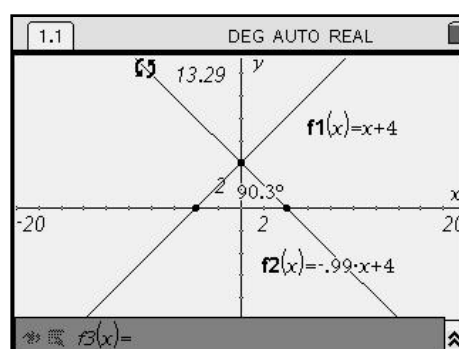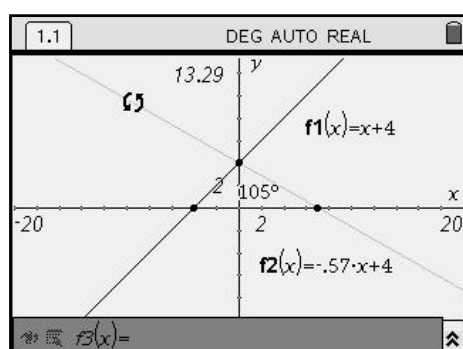
Figure 5.5-1 Screen grab 1: [PSH3(tns-T)]   Figure 5.5-2 Screen grab 2: [PSH3(tns-T)]

The resulting image enabled the students to use geometric reasoning to conclude that the lines generated by the two functions were perpendicular, based on what they knew about the properties of the isosceles triangle created by the points where the lines intersected with the axes. This helped the students to overcome the cognitive conflict caused in various instances when the degree of accuracy of the measured angle did not give an expected answer and they were less distracted by this when forming their conjectures. Sophie's detailed evaluation of the students' mathematical learning in this lesson, focussing on the process skills is included in Appendix 11.8. Although the academic discourse on how dragging within a geometric environment influences mathematical thoughts and actions is well documented (Arzarello et al. 2002; Holzl 1996; Mariotti 2001; Olivero 2003), this example provides some evidence for how the notion of dragging a function could change approaches to teaching and learning within mathematics. In addition, there is a merging of algebraic and geometric approaches, with the teacher and students using both domains to support them to generalise from what they were experiencing and observing.

5.5.6

Towards the end of the project, three teachers adapted the approach described in the "First steps with TI-Nspire™" booklet (Texas Instruments 2008) to develop lessons that provided opportunities for students to explored the relationships between the radius, diameter, circumference and area of a dynamic circle, [STP4], [LSMF5], [BBAK8]. Annie's lesson has already been described in Section 5.2. Malika also developed the same lesson and evaluated it as "technically over-ambitious" [LSMF5(LEval-T)]. She wrote that, although she thought the planning and preparation for the lesson was sufficient, "it is too much for one lesson, so maybe it should be delivered in two lessons" [LSMF5(LEval-T)].   This was corroborated by her mentor, who commenting on the

nature of the teacher intervention, observed that there was "none on looking at, and drawing inferences from the data" [LSMF5(LEval-M)]. However the lesson was positively evaluated by both because the students had "ownership of the construction, hence a belief in the data" [LSMF5(LEval-M)]. Despite having to follow a complex set of instructions [LSMF5(Task)], the students had created a series of linked mathematical objects and they showed "satisfaction when the connections were made and the relationships set up" [LSMF5(LEval-T)] and were "very pleased and surprised by the automated data collection" [LSMF5(LEval-T)]. In starting to use the advanced features of the TI-Nspire™, the students were beginning to appreciate some deeper fundamental mathematical concepts through the use of the dynamically linked multiple representations.

5.6 Equity and accessibility

5.6.1

The notions of equity and accessibility as defined by Hiebert et al (1997) stem from the premise that "each student can, and has a right to learn mathematics with understanding", something that all of project teachers agreed with when responding to the online teacher survey. Hiebert et al describe the related core features of effective mathematics classrooms as being those where the tasks are accessible to all students, where every student has the opportunity to be heard and every student contributes to the learning that is taking place.

5.6.2

Within the TI-Nspire™ lessons, the teachers were asked to evaluate how accessible the tasks were to students using the question "Approximately how many of the students could develop strategies to fully pursue the activity with little or no guidance from you?", followed by a prompt to describe the nature of the guidance and interventions they made for those students who needed more support. Of the sixty-one lessons, teachers offered a range of responses from "Almost all students could pursue the activity, two or three had problems with how to insert text for the centre of enlargement" [STP5(LEval-T)] to "most (85%) needed teacher/adult support or intervention – many of the interventions were to enable the students to use the grab had in the Geometry screen which they had not used before" [CEL3(LEval-T)]. By far the majority of the interventions described by the teachers related to the use of the correct syntax, navigation or manipulation procedures, with only a few relating to the mathematics underpinning the task itself. This was consistent with the research setting in that, for most of the lessons reported, the teachers and students were using features of TI-Nspire™ for the first time.

The nature of the TI-Nspire™ lessons that emerged through the course of the project meant that, as student autonomy was increasing through the use of more exploratory tasks, so the number of possible outcomes increased and the teachers had to find ways of accommodating this. There were several teachers who used lesson plenaries to enable students to share their conjectures, with the teacher mediating the discourse to support the students to reach conclusive statements. For example in the lesson "Fraction addition" [HAC4(LEval-T], Andrea encouraged the students to share their explanations, resulting in the students questioning each other until they were satisfied with the result.

The use of the Notes application was used by several teachers to encourage students to record their findings as well as their personal responses to TI-Nspire™ tasks. One girl, commenting on how the lesson was different, said it was not usual to "write your thoughts, ideas and feelings" in mathematics lessons [CHS1(LEval-S]].

Many teachers commented on the way that the TI-Nspire™ tasks supported students to work at their own pace ([HAC2], [BBAK3], [BBAK4], and [SJK1]) and none of the teachers reported that this pace was slower than expected. For example, Annie, commenting on her lesson [BBAK4] "Angles" said, "Exploration of the task was great. Students liked being able to work ahead and do as much as they could" [BBAK4(LEval-T)]. This provides sound evidence that the teachers considered the use of TI-Nspire™ to support individual pathways for learners through tasks. Where students had opportunities to decide how they were going to structure their mathematical enquiry, making choices about which applications within TI-Nspire™ to use and how they might present their work within the TI-Nspire™ file, both the teachers and students were very positive about the outcomes in terms of both the students' mathematical engagement and their learning outcomes. Writing about the lesson "Investigating straight lines", Annie commented,

> *The students were able to investigate easily, and write notes on things they found immediately using the Notes pages. They were able to investigate at their own pace and choose their own equations to explore. It was interesting to get them to just investigate and find things out without actually knowing anything about gradient and intercept.* [BBAK-JJ3(LEval)]

Annie included the following example of one of her student's comments,

if you add y= x+1 it will always go past the 1 on the y axses [sic] and -1 on the x axses. the same with y=x+2 it will always go past 2 on the x axses and -2 on the y axses. [BBAK-JJ3(tns-S)]

She concluded that these early explorations provided her year 7 students with a valuable introduction to straight line graphs that could be developed further in year 8.

6 Teachers' professional learning

Unlike other current research into the use of TI-Nspire™, the aims of this project were not to produce an exemplar "resource model" (Aldon et al. 2008) or to contrast students experiences using multi-representation technology (Arzarello & Robutti 2008), but the study sought to gain an insight into the teachers choices and actions in beginning to implement TI-Nspire™ technology in their classrooms. This was to gain a naturalistic sense of what teachers do with new technology in the classroom and how they evaluate its effectiveness with learners. In reviewing the project data, whilst it is possible to separate the occurrences of teachers' subject knowledge development from those learning incidents relating to their developing pedagogic knowledge, as they happened simultaneously, it is more useful to describe the circumstance and process through which this happened. By having a greater understanding of this, all those involved in supporting teachers' professional learning involving technology may begin to appreciate why barriers to technology use exist and what professional experiences help to overcome these barriers.

As in previous studies (Laborde 2001a; Noss et al. 1991; Pope 2001; Rodd & Monaghan 2002), this research has revealed the importance of collaborative opportunities for teachers developing their use of technology by providing time for teachers to:

- become personally acquainted with the technology in a supported environment;

- consider how to integrate technology within schemes of work, albeit in an evaluatory capacity with a view to developing teaching activities and approaches over time;

- appreciate when, and when not to use technology;

- become more knowledgeable about planning for students' progression both mathematically and in terms of developing their technical expertise with technology;

- develop strategies to support colleagues to develop their use of technology.

It is very common for teachers engaging in professional development activities away from their classrooms to conclude that the most valuable aspect of the experience is the time to talk and work with other teachers. Of the available 30 hours that the teachers and the project team worked together, over 20 hours were spent doing this, often

alongside their mentors, sometimes in just their school pairs and other times in mixed school groups. The nature of this dialogue fell into the following categories:

- o Learning to use TI-Nspire™ and developing lessons for the classroom;

- o Evaluating classroom outcomes and refining classroom materials;

- o Managing TI-Nspire™ technology in schools;

- o Strategies for supporting other colleagues to use TI-Nspire™.

6.2 Teachers learning to use TI-Nspire™ and developing lessons for the classroom

6.2.1

From the moment the teachers first switched on the TI-Nspire™ handheld (or loaded the software), a key principle for the design of professional development sessions focused on using the technology to solve interesting mathematics problems whilst becoming familiar with the functionality. In designing these sessions, the project team spent time considering carefully the teachers' prior experiences and levels of confidence with mathematics educational technology and grouped teachers and mentors in a way that would lead to the most appropriate level of challenge and support for different tasks. For example, four of the teachers were confident users of the dynamic geometry computer software "The Geometer's Sketchpad" (Key Curriculum Press 2003). The team knew that, as the TI-Nspire™ Graphs and Geometry application was based on Cabri-Geometry (Baulac et al. 1988), these teachers would encounter a certain level of discomfort as they came across subtle differences in syntax.

6.2.2

There was certain syntax that was unfamiliar to some of the teachers, who had no previous experience of using technology to define functions and sequences. For example, using the notation $f(x):=2x+3$, to enable the function to be evaluated using different values of x, i.e. $f(3)$, which would then return the output 9. Several teachers expressed concerns that their students would find this notation difficult. However, one school developed several lessons with their mentor that exploited this functionality, such as [LSSM1] "Digit sums" and [LSSM2], "Trial and improvement". Lesson evaluations from the teachers and mentor, although mentioning that interventions were required to support some students to use the syntax was needed, stated that the use of such notation was powerful in allowing the students to access many mathematical examples quickly, supporting the process of generalisation. The lesson "Trial and improvement" [LSSM2], [LSMF3] was a good example of how the use of function notation allowed the

students to explore the concept of the meaning of the "roots" of a quadratic function. The teachers were able to focus their students' attention towards interpreting their results, and representing these graphically, providing a valuable picture of what they had been doing algebraically. Figure 6.2-1 to Figure 6.2-3 detail the approach taken in this task and the teacher notes developed by the mentor to support this task are shown in Appendix 11.15.

Students began by defining a quadratic function in the Calculator application and substituted values into the function with the aim of finding a value for which the function equated to zero.

They progressed to substitute decimal and later, negative values.
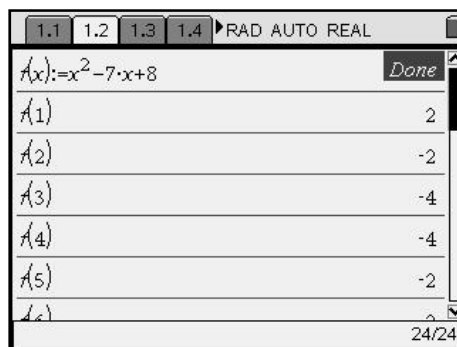
Figure 6.2-1 Calculator page [LSSM2(tns-T)]

The students moved to the Spreadsheet application where they defined column A as variable x, and column B as variable y.

They entered values for x into column A before defining cell A1 as equal to $A1^2-7A1+8$ and using Fill down to evaluate the function.
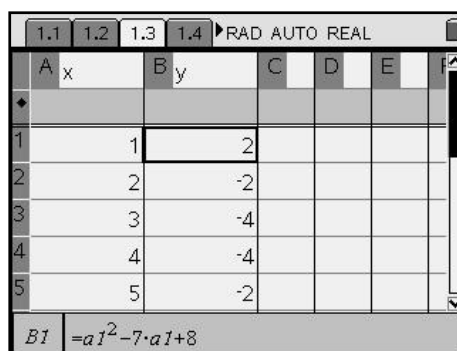
Figure 6.2-2 Spreadsheet page [LSSM2(tns-T)]

Finally, the students moved to the Data and Statistics application where they linked the scatter plot the variables x and y, as previously defined in the Spreadsheet application.
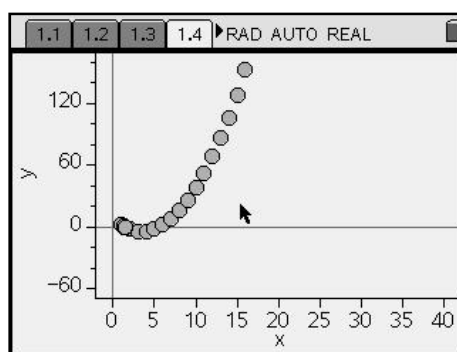
Figure 6.2-3 Data and Statistics page [LSSM2(tns-T)]

During the project, all of the teachers became interested in the design of tasks to varying degrees, actively seeking to learn the syntax and key manipulations to produce their own TI-Nspire™ files. None of the teachers wanted simply to be given a TI-Nspire™ file to use with a class without having some awareness of how the .tns file worked. A rich stimulus for this process was the transfer of existing task ideas (with and without technology) to involve the use of TI-Nspire™. The early lessons, [CEL2, PCT3, CHS2] "Triangle angles", [CE1, PCT3] "Quadrilateral angles" and [CEL3, CHS4, PCT3] "Intersecting lines" were typical examples of lessons developed in this way. However, this prompted the project mentors to clarify their role in relation to this aspect of their support. Rather than use their personal expertise to design the best lesson they could, utilising all the useful functionality afforded by TI-Nspire™, they decided to act solely as an author, supporting the teachers to design the task and meet the teachers' specifications as closely as possible. By doing this, they could be assured that the task used TI-Nspire™ functionality with which the teachers were comfortable. This meant that the mentors were not necessarily using the advanced features of TI-Nspire™, or reconsidering how TI-Nspire™ might allow the mathematics behind the task to be approached in a radically new way with the teachers at the outset. These discussions came later.

6.2.4

In the task [CEL2] and [PCT3] "Triangle angle", the teachers involved had asked for a task to enable the students to learn how to measure the interior angles of a set of triangles and enter the measurements into a spreadsheet to then find the angle sums. The request was for "a geometry activity linked to the scheme of work to develop students' skills using the geometry package" [PCT3(Refl-T)]. There was no request to use the drag functionality as the teachers thought that was beyond their expectations for the students in this lesson, given that it was to be one of their first lessons using TI-Nspire™.

The resulting task is shown in Figure 6.2-4 to Figure 6.2-7.
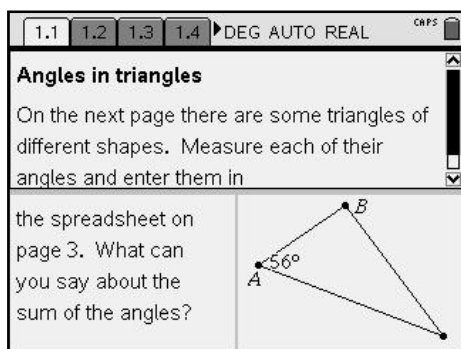
Figure 6.2-4 Page 1 [CEL2(tns-S) and PCT3(tns-S)]
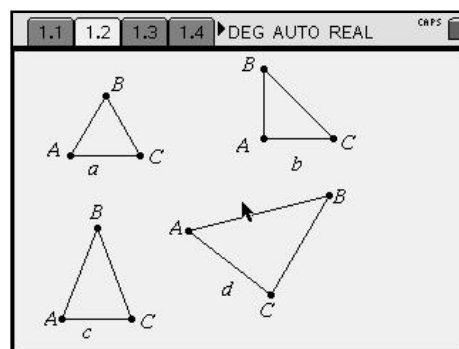
Figure 6.2-5 Page 2 [CEL2(tns-S) and PCT3(tns-S)]

Figure 6.2-6 Page 3 [CEL2(tns-S) and PCT3(tns-S)]
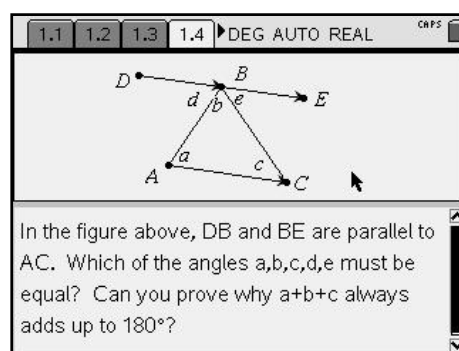
Figure 6.2-7 Page 4 [CEL2(tns-S) and PCT3(tns-S)]

In evaluating this lesson, one of the teachers was critical about the resulting TI-Nspire™ file, saying "the lesson files were too prescriptive – we had requested a lesson to use the geometry menu to allow pupils to measure accurately and spot themselves which [angles] were equal/added to 180°" [PCT3(Refl-T)]. An interpretation of this response could be that the teacher faced a conflict between the need for students to practice the new TI-Nspire™ skill of measuring an angle using the Geometry application and wanting them to appreciate the power of the dynamic environment through dragging a geometric figure. The progression in this dialogue with the group led to a series of consolidation activities within a TI-Nspire™ file "All angles recap" [CEL3(tns-S)], in which Eleanor revisited the original contexts and created dynamic figures which the students explored for themselves and arrived at their own conclusions.

6.2.5

Where the teachers in the project had a shared vision for the use of TI-Nspire™ within their classrooms, they were more able to work collaboratively to develop tasks and approaches towards this aim, and had a more systematic approach to evaluating their own and their students' progress. For example, the teachers at Lime Street school

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privileged student autonomy, saying that they wanted students to solve problems for themselves, encouraged problem solving activities in which the students were expected to work towards "finding an acceptable resolution" [LSMF(Refl-T)].

Throughout the study, there were several instances where objects within TI-Nspire™ files did not behave as expected and the project group worked together to discuss and amend the .tns files, seeking support from the technical team where needed. The group also had to respond to a (much welcomed) operating system upgrade partway through the project, which resulted in a number of software improvements and bug fixes and introduced some changes in syntax. This also meant that the teachers had to become familiar with the procedures for upgrading the individual handhelds and computer software and also be aware of the compatibility of existing files and peripherals, such as the overhead projector ViewScreen. Whilst it was assumed that all of the schools had appreciated the importance of carrying out these procedures and the strategies for doing so, it was apparent from the mentors' visits to the schools that not all schools had been able to implement these upgrades or that some had omitted to upgrade all of their equipment.

6.3 Evaluating classroom outcomes and refining classroom materials

6.3.1

The time spent evaluating classroom outcomes and considering how to refine TI-Nspire™ files and support materials formed a significant part of the teachers' work throughout the project. These focused upon:

- o   the management of the technology in the classroom;

- o   whether the learning outcomes that had been planned had been achieved;

- o   whether the design of the TI-Nspire™ activity had "worked" and how it might be improved and/or adapted;

- o   the difficulties that teachers and/or students had experienced in their uses of TI-Nspire™ during the lesson;

- o   the general feelings of both students and teachers with respect to the lessons as a whole;

- o   personal reflections on behalf of the teachers with respect to what they might do differently next time.

The teachers completed the TI-Nspire™ lesson evaluation proforma (see Appendix 11.7 and Appendix 11.8) with varying amounts of detail. However the basic structure of the questionnaire elicited sufficient information to determine the nature of use the TI-Nspire™, the amount (and nature) of the teacher intervention required during the lesson and the teachers' evaluations of the students' learning outcomes. Teachers found the completion of the first part of the questionnaire far easier than the second, which required them to become increasingly familiar with the newly published National Curriculum (Department for Children Schools and Families 2007), and its emphasis on key processes. Although this proved to be challenging, it gave the teachers a much richer vocabulary to describe the nature of the mathematics with which their students had been engaged, as well as highlighting outcomes that they had not anticipated when designing the lesson.

6.3.2

The ability to systematically collect and review the TI-Nspire™ files at the end of the lesson, although only used by four teachers in the same two schools, resulted in much deeper evaluation of the students' lesson outcomes and enabled the teachers to consider more carefully the progression in both the mathematics they were teaching and the progression in the development of students' TI-Nspire™ skills. In the case of Bishop Brown School the combination of their use of TI-Nspire™ software, the school's wireless network and virtual learning environment allowed for smooth transfer of files between students and teachers as well as online self-evaluation of learning by the students.

6.3.3

The nature of the teachers' reflections on their TI-Nspire™ lessons often led them to explicitly critique their teaching approaches and suggest how these might change in the future. Writing about her lesson [SJK4] "Straight line graphs" (see Section 5.3 for a more detailed description), Judith said,

> The idea (I felt) was good it was my questioning that needed to improve. Rather than 'What do you think is happening?' I could say 'What has not changed to make this fan, what has stayed the same?' 'Where is the fan starting from?' [SJK4(LEval-T)]

On another occasion, reflecting on the design of the activity [GAS-BA4] "Introducing trigonometry" Amie wrote,

> From that lesson we learned that perhaps it was a little bit too complicated in the sense that we had ten different files to give out. We planned it quite carefully in that Becky and I would send 5 files out each to one pupil and then they would send it to five more. Maybe we would transfer the files before the

lesson, maybe we would give everyone the same file and then we could have told them how to change the angle. [GAS4(LEval-T)]

Both of these cases provide evidence of the professionalism of the teachers involved in the project and the degree to which they were not only reflecting on their practice, but providing honest written accounts within their project files.

6.3.4

Over the course of the project, the teachers had the opportunity to hear about nearly thirty TI-Nspire^TM tasks during the regular feedback sessions and these proved to be significant in seeding the development of new TI-Nspire^TM tasks, techniques and the associated teaching approaches. One such example was the lesson taught by Sophie [PSH3] "Gradient properties of perpendicular lines", which was described in detail in Section 5.5 and which she reported to the group at the November conference. All of the teachers in the group were intrigued by this lesson as it offered a new approach to this concept, which the teachers concluded they would normally have taught by giving the students the rule or by using graph plotting software or graphics calculators to guess and adjust functions. The use of the angle measurement facility, combined with dragging a linear function, was appreciated as an innovative use of the advanced features of TI-Nspire^TM.

Following the November project conference, Eleanor developed a lesson based on this approach to use with her key stage 4 class. (She later admitted that she had not taken detailed notes and was recreating the activity from her memory of Sophie's conference presentation.) Eleanor's approach differed from Sophie's in that, having defined the first linear function, she instructed her students to create the second line by constructing a freely drawn line from the Construction menu that looked perpendicular to the original line. They then continued to measure the angle between the two lines and adjust the geometric line, such that it looked perpendicular and an angle of approximately 90° was returned. Eleanor then asked her students to generate more lines that were parallel to this freely drawn line, using function notation, and to make some conjectures about what they found out. The student outcomes from Eleanor's lesson provided an insight into the process of generalisation made by students as they made sense of the diagrams they produced.

Eleanor commented on how she was surprised that several of the students produced many perpendicular lines before being convinced enough that what they were observing could be generalised. This appears to evidence the students' needs to consolidate their understanding of the gradient properties of parallel lines within the task, whilst enabling them to engage with a new mathematical concept.
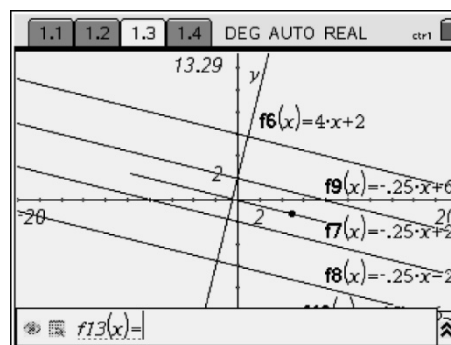
Figure 6.1 Gradient properties of perpendicular lines: Student's work

6.4 Managing TI-Nspire™ technology in schools

6.4.1

Whilst the teachers welcomed the professional conversations and experiences during the project conferences, many of them found it difficult to sustain their enthusiasm and commitment when they returned to school. Where they had dedicated time to meet and work together in their school pairs, often supported by their mentor, they were able to continue to develop tasks and approaches as well as evaluate and refine existing ones. The teachers who did collaborate with each other did so during planning, preparation and assessment time, or through impromptu arrangements. Where the schools had shared department meeting space, the teachers valued this facility and cited it as being instrumental in facilitating collaborative planning. In one school, where the senior management team took an active interest in the TI-Nspire™ project, the teacher gained significant recognition and professional praise for her involvement, resulting in an innovation award being made to the school.

6.4.2

Not all of the teachers had the technical awareness to appreciate the significance of the necessary ongoing maintenance of the TI-Nspire™ handhelds, software and peripheral devices. Consequently, most schools met technical difficulties at some point which, although not insurmountable, could have been avoided. As a battery operated device, the TI-Nspire™ demanded similar management procedures to graphical calculators, except that schools were used to ordering batteries for graphical calculators on an annual basis, rather than a termly one. Only one of the project teachers had ever upgraded the operating system for a handheld device previously, so this was a new procedure that the teachers had to familiarise themselves with. In their final evaluation, all of the teachers felt that there was a need for their school's IT support services to be

engaged in these sort of processes, particularly as many of them did not have administrative rights for their school computers.

Although all of the schools had a dedicated mentor to work with them for the duration of the project, not all of the schools took full advantage of this expertise and they were aware of this. This was captured by Sophie who wrote, in response to a question about the adequacy of her planning and preparation for the lesson [PSH5] "Enlargements",

> *Adrian came in and helped to produce a rectangle of exact measurement 1 X 2 - To an extent, I did as much as my technical abilities would allow in the time that I had. If I had asked for technical help earlier I could have transferred the doc before the lesson.* [PSH5(Refl-T)]

The provision of a mentor relies upon the teacher knowing what question to ask to enable them to make progress in what they want to do. Where the article under discussion is a new technological tool, with a vocabulary that is unfamiliar and techniques even more so. Sophie captured this by saying "It takes time to know what to ask." [PSH(Refl-T)]. Another teacher added, "timing is an issue – more planning ahead is required" [CEL(Refl-T]], which suggests that the provision for dedicated planning time for the department could also involve the mentor's support from time to time.

6.5 Strategies for supporting colleagues to use TI-Nspire™

Towards the end of the project, the teachers were asked to reflect upon their own experiences in learning to use TI-Nspire™ in the classroom and to consider how they might enable colleagues in their departments to learn to use TI-Nspire™. The teachers saw that organising a dissemination opportunity for their colleagues might inform them about TI-Nspire™, but most thought that they would need to find opportunities to replicate their own experiences through a cycle of activities over two or three terms. They were unanimous in that they could not just disseminate in a telling sense by simply passing on information or verbally. The teachers and their mentors developed the following list of possible actions:

- o inviting colleagues into their classrooms to observe a TI-Nspire™ lesson and then pair up to plan an teach the same lesson with the colleague's class;

- o provide each teacher with their own TI-Nspire™ handheld and arrange for the TI- Nspire™ software and TI-Nspire™ computer link software to be loaded onto their school computer;

- o use the "First steps with TI-Nspire™" (Texas Instruments 2008) booklet with teachers;

- o include TI-Nspire™ professional development as a strand on the department's development plan and use this to communicate to senior colleagues the need for time for the department to meet;

- o involve a senior colleague in the evaluation process and to support the Head of Department where needed;

- o team teach two classes together, with the more experienced teacher taking a leading role;

- o use a hands-on session during department meeting time to introduce one or two TI-Nspire™ activities that will then go into the next term's scheme of work; use dedicated time for the teachers to pair up and evaluate these lessons and/or support each other;

- o sharing lesson plans and TI-Nspire™ files with colleagues through the school network and TI Resource Exchange.

7 Conclusions

The project's aims were to question how TI-Nspire™ might support students to learn mathematics with understanding and to identify the features of an effective professional development experience for teachers learning to use TI-Nspire™ technology in their classrooms.

7.1 How does TI-Nspire™ support students to learn with understanding?

7.1.1

The evidence from this study is primarily based on teachers' own accounts, triangulated by students and mentors. The term "learn with understanding" is interpreted within the framework offered by Hiebert et al (1997), and this study has reported a wealth of classroom evidence for the way in which TI-Nspire™ can support students to learn in this way. Although this study did not set out to quantify the impact of the introduction of TI-Nspire™ technology on secondary students' mathematical learning through gains in test scores, the qualitative evidence provided by the analysis of the sixty-one reported lessons revealed that those which were highly evaluated by the teachers contained elements of "rich mathematical tasks" as described by Ahmed (1987). The features of such tasks are that they:

- o *must be accessible to everyone at the start;*

- o *needs to allow further challenges and be extendible;*

- o *should invite children to make decisions;*

- o *should involve children in speculating, hypothesis making and testing, proving or explaining, reflecting and interpreting;*

- o *should not restrict children from searching in other directions;*

- o *should promote discussion and communication;*

- o *should encourage originality/invention;*

- o *should encourage "what if?" and "what if not?" questions;*

- o *should have an element of surprise;*

- o *should be enjoyable.* (Ahmed 1987)

In the TI-Nspire™ lessons the technology was increasingly used to stimulate students to think mathematically and, in many cases, begin to engage strongly with mathematical

structures and concepts in way that is normally not possible with traditional paper and pencil approaches. In addition, the teachers and students spoke of increased autonomy, particularly where the students had developed sufficient confidence with TI-Nspire™, to enable them to determine their own pathway through a task. Teachers also said that the technology had motivated their students by promoting their natural interest and intrigue in the mathematics itself. Finally, the teachers described increased opportunities for the formative assessment of their students' mathematical understanding, promoted by the use of the technology. This finding was corroborated by students' lesson evaluations.

Access to rich mathematical tasks

7.1.2

As the project progressed, all of the teachers professed that the nature of their planned lessons had shifted to offer the students a more exploratory learning experience with a change in the mathematical emphases within tasks. This is supported by the analysis of lesson data as outlined in Appendix 11.13 and the observations of the mentors and project team. The teachers reported that TI-Nspire™ had helped them to design tasks which supported students to focus their attention on identifying mathematical relationships and making mathematical connections. The observable shift was that teachers were providing more opportunities for their students to use TI-Nspire™ as a resource to support their students to make and test conjectures with mathematical generalisation as the ultimate goal across the age and ability range.

7.1.3

Just over a quarter of the lessons involved the use of a mathematical representation within a single TI-Nspire™ application. In all of these cases, TI-Nspire™ was acting as a black box to support student exploration, acting as a neutral tool which gave the students non-judgemental feedback and supported them to follow their own lines of enquiry. Analyses of such lessons revealed that inherent in the lesson design were the opportunities for students to experience incidental cognitive conflict[7], provoked by the technology.

7.1.4

By the end of the project, most of the teachers had developed at least one TI-Nspire™ lesson that involved the use of the grab hand to select a mathematical object (point, geometric line or movable line) and drag it to a new position, with the emphasis on close

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[7] None of the teachers reported that they had designed any TI-Nspire™ with the specific intention of promoting cognitive conflict, although this may have been an implicit feature of an individual teacher's personal teaching approach.

observation of the outcome as a means to identifying mathematical relationships. These lessons spanned the curriculum content and were positively evaluated by students as providing rich learning opportunities. Some teachers reported that the notion of dragging mathematical variables appeared to be a new experience for the students and, as such, provided a good opportunity for eliciting mathematical surprises. The findings with respect to teachers adoption of dragging as a pedagogical tool were consistent with other studies that have probed teachers uses of dynamic geometry software, for example, Ruthven et al (2004).

7.1.5

Some teachers also commented favourably in relation to the students' retention of mathematics learned during TI-Nspire™ lessons. They evidenced this through their students' responses during whole-class plenary discussions and when questioned about the mathematical concepts at a later date. The teachers also reported that, where TI-Nspire™ had promoted exploration, the resulting discussions provided a strong motivation for the students to record their own findings and, in doing so, actively participate in tasks at a much higher level. Pupil motivation was improved because the students achieved a greater level of satisfaction by being engaged in complex mathematical thinking, which provided a sense of purpose for the classroom discourse.

7.1.6

Within the TI-Nspire™ lessons, the teachers were asked to evaluate how accessible the tasks were to students. By far the majority of the interventions described by the teachers related to the use of the correct syntax, navigation or manipulation procedures, with only a few relating to the mathematics underpinning the task itself. This was consistent with the research setting in that, for most of the lessons reported, the teachers and students were using features of TI-Nspire™ for the first time. Teachers initial reservations about how their students would make sense of certain TI-Nspire™ syntax and keyboard procedures were generally unfounded, with the majority reporting surprise at how adept their students were with the technology. However, many students who used the handheld did comment on how they would like a QWERTY keyboard, a plug-in mouse and a touch screen.

TI-Nspire™ changing the classroom ethos

7.1.7

The nature of the TI-Nspire™ lessons that emerged through the project meant that, as student autonomy was increasing through the use of more exploratory tasks, so the range of learning outcomes increased. Teachers reported an emphasis on collaborative

whole-class learning and students were often recording their work on paper, in exercise books or using the Notes application.

As the teacher's familiarity with the affordances of TI-Nspire™ as a tool developed, they became more confident to allow the students to determine their own mathematical path. By placing more emphasis on students' peer and self-assessment, often utilising the Notes facility within TI-Nspire, group tasks and whole class plenaries, the teachers developed strategies which reflected a greater confidence that learning was taking place and were able to evidence this. Consequently the students were learning to work more independently from their teacher.

7.1.9

Students participated in lesson plenaries, not solely held at the end of lessons, to share their conjectures with the teacher mediating the discourse to support the students to reach conclusive statements. The teachers' lesson evaluations included many comments relating to their observations of a change in the classroom ethos, which promoted students to take more responsibility for their mathematical learning.

7.1.10

There were a few occasions when the teachers chose to centrally involve the students in supporting each other to troubleshoot the technical difficulties they encountered. These classrooms reflected an ethos in which the students own contributions were highly valued by their teachers and the teachers were flexible in the way students used their learning space, trusting them to make sensible choices to enable them to achieve the desired mathematical outcomes. In both cases, this was made more possible by the portability of the handhelds and laptops which offered a distinct advantage over a fixed computer suite arrangement.

Supporting mathematical communication

7.1.11

As the exploratory use of the technology had stimulated mathematical discussions, the teachers were able to listen carefully to their students and, in doing so, support the development of their students' mathematical vocabulary and the communication of their emergent mathematical ideas. In some cases, the TI-Nspire™ technology directly supported the development of this vocabulary as students adopted the terminology used within the TI-Nspire™ application menus. The occasional differing mathematical terminology between UK English and US English, for example "enlargement" and "dilation", was viewed as an opportunity to promote the cultural aspect of the language

of mathematics by some teachers and as a source of possible confusion for students by others.

7.2 How does TI-Nspire™ support teachers' professional development?

7.2.1

The project has provided clear findings with respect to the professional development experience for teachers learning to use TI-Nspire™ for classroom use, substantiated by the teacher's individual and group reflections and triangulated by the project team's observations. Three clear stages emerged. Firstly, the teachers became familiar with TI-Nspire™; secondly they started to experiment in the classroom and finally, they adopted a more critical approach to their classroom use of TI-Nspire™ as their own knowledge, skills and confidence developed. The outcomes had much in common with previous studies that have reported on the professional development journeys of teachers involved in the introduction of new technologies in mathematics classrooms (Noss et al. 1991; Stradling et al. 1994; Sutherland 1998). However, there were some findings which were specific to the introduction of TI-Nspire™, which form the focus for the conclusions for this study.

Early responses to TI-Nspire™

7.2.2

The teachers' initial reactions to the TI-Nspire™ handheld were influenced by their previous uses of technology. In the early professional development sessions, the project mentors' roles were crucial in supporting the teachers to gain familiarity with each application, whilst considering how the functionality might be utilised to develop classroom tasks. It was important that each project mentor listened carefully to the teacher's own questions and supported them to both explore the functionality, whilst offering suggestions in response to the teaching and learning opportunities that were emerging. However, one teacher's comment, "It takes time to know what to ask", captures the dilemma relating to the role of the mentor when the pace of support is led by the teacher.

7.2.3

The early TI-Nspire™ activities often replicated tasks which were already familiar to the teachers from their previous experiences, sometimes from the use of other software environments. This finding is consistent with previous research into the introduction of new technologies for mathematics, for example the use of dynamic geometry software,

(Laborde 2001a; b). These early lessons tended to use a pre-constructed TI-Nspire[TM] file, often developed in close collaboration with mentors and, although the tasks did not necessarily transfer smoothly to the TI-Nspire[TM], the subsequent professional conversations led to refined versions of the same tasks, often using more advanced TI-Nspire[TM] functionality. Although these lessons were favourably evaluated in terms of both the students' positive attitudes and their mathematical learning outcomes, they did not necessarily exploit any of the advanced functionality of TI-Nspire[TM]. However, they did prove to be valuable classroom experiences for several of the teachers at an early stage of the project, as they were becoming more familiar with TI-Nspire[TM] and managing its use in the classroom with learners.

7.2.4

Early tasks that used multiple TI-Nspire[TM] applications did not necessarily link variables between applications, although these tasks stimulated the discussion about what and how variables could be linked and what mathematical and pedagogical advantages this might offer for teachers and learners. A few teachers expressed the concern that there might be classroom scenarios where a more time-consuming practical approach might be initially better than using dynamically linked variables across several applications. They thought that, with too many on-screen changes happening simultaneously, students might need more time to absorb what was happening on screen. The teachers involved in the laptop pilot commented that the handheld's slower interface could offer a pedagogical advantage over the software in such situations.

7.2.5

Most teachers began to link variables within the Spreadsheet and Data and Statistics applications, which, by design, required them to assign the columns of data with variable names. The selection of the variables to graph using the drop down lists enabled both teachers and learners to utilise this functionality easily.

7.2.6

It was very evident to all of those involved in the project that, if the aim for the linking of variables was to provide mathematical insight into a context or problem, the majority of the teachers had very little knowledge or experience of:

  o   when the linking of variables might be useful;

  o   which variables could (or should) be linked;

  o   how to carry out the technical steps needed using TI-Nspire[TM].

Amongst the project team, there was slightly more expertise in this area, but as the project data reveals, learning to use the applications within TI-Nspire[TM] in an integrated

way proved to be a time-consuming process and there were few teachers with the confidence and technical skills to embark on this within the first few months of the project.

Reflecting on and through practice

7.2.7

The time spent in collaborative professional dialogue was most valued by the teachers in the project. Their discussions focused upon: the management of the technology in the classroom; evaluation of learning outcomes; refining TI-Nspire™ files; overcoming usability issues; developing ideas for future lessons and formulating their personal responses to planned professional development tasks. The study provided strong evidence from multiple sources to conclude that learning to use TI-Nspire™ provided a rich context for teachers' professional development that went beyond just learning to use the technology.

7.2.8

The nature of the teachers' reflections on their TI-Nspire™ lessons often led them to explicitly critique their teaching approaches and suggest how these might change in the future. Both of these provide strong evidence for the professionalism of the teachers involved in the project and the degree to which they were not only reflecting on their practice, but were prepared to share this more widely by providing honest written accounts within their project files. There was variability in the depth of reflection by individual teachers with some teachers more able to evidence their claims systematically than others. The teachers own classroom examples provided the stimulus for the regular feedback sessions. These proved to be significant in seeding the development of new TI-Nspire™ tasks, techniques and the associated teaching approaches. Some teachers used the TI-Nspire™ functionality to systematically collect and review the students' TI-Nspire™ files at the end of the lesson, which resulted in much deeper evaluation of the students' lesson outcomes and enabled the teachers to consider more carefully the progression, in both the mathematics they were teaching and the parallel development of students' TI-Nspire™ skills. This was utilised effectively by the laptop school, providing an insight into how the availability of wireless classroom networking for the handhelds might offer significant advantages for the smooth transfer of files between students and teachers in the future, supporting both the formative and summative assessment processes.

7.2.9

The TI-Nspire™ lesson evaluation proforma elicited sufficient information to determine the nature of the use of TI-Nspire™, the frequency and type of teacher intervention

required through the lesson and the teachers' evaluations of the students' learning outcomes. In doing so, the teachers became increasingly familiar with the newly published National Curriculum (Department for Children Schools and Families 2007), and its emphasis on Key processes. Although evaluating lessons in this way proved to be challenging, it gave the teachers a much richer vocabulary to describe the nature of the mathematics with which their students had been engaged as well as highlighting outcomes that they had not anticipated when designing the lesson.

7.2.10

Over the course of the project, several teachers commented explicitly on a reduction in their own need to pre-teach the mathematical content in a traditional way, or provide extensive task instruction before allowing the students to use TI-Nspire™. This suggests that these teachers were growing in their confidence that the students would learn through their use of the technology, without the need for high levels of teacher intervention and direct teaching or over-structured tasks.

7.2.11

In developing their classroom activities with TI-Nspire™, teachers began to consider the nature of the support that they needed to provide to enable students to be able to work independently from them. Teachers developed whole class teaching materials, typically using their interactive whiteboard software to provide essential information, as well as prompts within the TI-Nspire™ files and accompanying paper resources.

7.2.12

Making choices about what constituted the essential information to share with the students within a lesson that uses Ti-Nspire™ presented the teachers with a number of key decisions:

- o How much technical instruction was needed in order to set up a task?

- o How should the teacher mediate this? from the front of the classroom? through a set of task instructions? using the Notes pages within the student's .tns file?

- o At what point should the teacher intervene during the lesson if students appear to be experiencing technical difficulties in achieving the mathematical aims?

- o How is it best to manage these interventions?

7.2.13

Towards the end of the project nearly all of the teachers were seeing the value of including specific learning objectives which related to developing the students technical fluency with TI-Nspire™. These teachers showed a much greater awareness of their

students' previous experiences with TI-Nspire™ and the progression in students' TI-Nspire™ technical skills. The teachers were also becoming more confident at choosing when to, and when not to, use the technology, with many stating that their ideal end point was for their students to have enough technical fluency to be able to make this choice for themselves.

7.2.14

Two teachers reported that their experiences during the project had prompted them to fundamentally rethink how they would approach the teaching of certain mathematical topics, even if they were not using technology, favouring a more student-centred exploratory approach over direct teaching approaches.

7.3 Considerations for schools adopting TI-Nspire™ technology

This study did not intend to research the factors that support schools to adopt TI-Nspire™ technology, however the teachers' and mentors' reported experiences have revealed some findings at school level which are worthy of inclusion.

7.3.1

Where the teachers in their school pairs had a shared vision for the use of TI-Nspire™ within their classrooms, they were more able to work collaboratively to develop tasks and approaches towards this aim, and had a more systematic approach to evaluating their own and their students' progress. The technology alone could not rise above this vision and the limiting factors were each teacher's pedagogic content knowledge and personal beliefs.

7.3.2

Where the teachers had dedicated time to meet and work together in their school pairs, often supported by their mentor, they were able to continue to develop tasks and approaches as well as evaluate and refine existing ones. The teachers who did collaborate with each other did so during planning, preparation and assessment time, or through impromptu arrangements. Where the schools had shared department meeting space, the teachers valued this facility and cited it as being instrumental in facilitating collaborative planning. Whilst this is true of any curriculum development initiative, the introduction of TI-Nspire™ technology presents a considerable challenge to teachers which is ideally supported through such collaborative work.

7.3.3

The majority of teachers in the group had no experience of managing a set of handhelds and found the process of maintaining batteries, and operating software and peripheries,

cumbersome. The teachers commented that at school level, this service would be better provided by dedicated support from the school's IT support services.

7.3.4

The provision of a mentor relies upon the teacher knowing what question to ask to enable them to make progress in what they want to do. Difficulties can arise for instance, where the article under discussion is a new technological tool, with a vocabulary that is unfamiliar and techniques even more so. One teacher said, "timing is an issue – more planning ahead is required", which suggests that the provision for dedicated planning time for the department involving the support of an external expert is required for the teachers to make faster progress.

7.3.5

The teachers offered a range of suggestions for how they might enable colleagues in their departments to learn to use TI-Nspire^{TM}. The teachers saw that organising a dissemination opportunity for their colleagues might inform them about TI-Nspire^{TM}, but most thought that they would need to find opportunities to replicate their own experiences through a cycle of activities over two or three terms. They were unanimous in their view that they could not only disseminate by just informing colleagues about the project. The teachers developed a useful set of actions for other schools to consider taking. (detailed in Section 6.5)

7.3.6

Many teachers saw the benefit of the students making their own notes and observations within their TI-Nspire^{TM} files. This raises an issue for teachers and schools with respect to managing the students' access to a particular TI-Nspire^{TM} handheld, where the resource is shared within a department. Students owning their own TI-Nspire^{TM} would have a distinct advantage as they would be able to revisit previous tasks for revision, continue tasks begun in school at home, and also have the opportunity to transfer their class work on the handheld to their home computer, if they had access to one.

7.3.7

As in previous projects involving the introduction of new technologies to mathematics, the time taken for teachers to assimilate TI-Nspire^{TM} into their classroom practices should not be underestimated, and although the teachers reported that they needed between one and eight weeks of TI-Nspire^{TM} use to be confident enough to use the technology in the classroom, the project data revealed that the majority of the teachers were only just beginning to realise the potential of the technology, in particular to make

educational use of its multiple linked representations during the final few weeks of the data collection period.

Finally, the relatively recent Ofsted subject report for mathematics (2005) made the following comment with respect to students' access to ICT within subject areas:

> *In the most effective schools, consideration is given to the range of uses of ICT for each subject area. Use of good whole-class projection and presentation facilities, including interactive whiteboards where available, are viewed as an addition to pupils' access, individually or in pairs, to computers with suitable software on them. The more innovative schools have overcome the pressure on specialist ICT rooms by placing ICT suites within departments around the school, or by imaginative use of wireless technology based in departmental areas.* (Office for Standards in Education 2005)

TI-Nspire^{TM} offers a tangible solution to this issue for mathematics departments, through a portable handheld device which has the functionality to satisfy the mathematics ICT needs of the key stage 3 and 4 mathematics curriculum. Whilst the professional development implications for mathematics departments are initially significant, the project evidence has demonstrated that all of the teachers, with varying levels of support, were able to utilise its functionality for the advantage of their learners. After eight months of classroom use with students, the teachers and students were beginning to use the advanced functionality in particular, dragging mathematical objects (vertices of shapes, movable lines and functions) and linking variables between TI-Nspire^{TM} applications.

7.4 Limitations of the study

7.4.1

The research study adopted a naturalistic approach to ascertain how teachers learned to use TI-Nspire^{TM} for use in secondary mathematics classrooms and how they evaluated the impact of these lessons on their learners' mathematical experiences, seeking evidence of improved mathematical learning. The teachers' own evaluations form the basis of the research data and, although mentor observations and the students' own evaluations offer some triangulation, the study relies principally upon the accounts, judgements and interpretations of the teachers themselves. To ensure the validity of the data, the research team provided prompts and probes to support the teachers to develop systematic methodologies, whilst accepting that the data they provided was an honest and professional account. There were seven lessons which were excluded from the data

as they were not considered to be sufficiently robust or where the teacher was unable to provide further information.

The research did not probe the students' previous use of technology to support their mathematical learning. Although the schools' contextual data and teacher questionnaires suggested high levels of technology use overall, little was known about the individual students' prior experiences in their mathematics lessons. The evaluation data from the students themselves suggests that accessing technology in their mathematics lessons was a new experience for some of them. The exceptions to this were three groups of older students (Year 11) who made direct comparisons between their lessons involving TI-Nspire™ and previous lessons that used graphic calculators or spreadsheets. Consequently, the study could not draw any conclusions with respect to the ease with which the students were able to transfer existing ICT knowledge and skills when beginning to use TI-Nspire™ technology

Finally, whilst it was hoped that the data from Greenmount School would provide some evidence about the students' experiences when they had access to a dedicated TI-Nspire™ handheld over several months, a change in teaching staff and difficulties surrounding the school management of the handhelds meant that they were unable to provide the data to enable a valid or reliable conclusion to be made. Despite initial enthusiasm from the teachers to code the TI-Nspire™ handhelds, allowing individual students work to be collected and tracked, the existing mechanism for transferring files between the handhelds and the teacher's computer was considered by the teachers to be too cumbersome to enable them to do this systematically.

7.5 Recommendations for future research

Further research is required to explore how the linking of mathematical variables within TI-Nspire™ applications changes the way that students interpret and communicate mathematics. A particular area of research might examine how students' attention is drawn to variables and the mathematical knowledge that they gain from such experiences. A parallel or separate study could focus on the teachers' perspective, seeking to identify how teachers make sense of this advanced functionality in order to create tangible classroom tasks.

7.5.2

A further study is needed to research models of school-based professional development involving TI-Nspire™ within whole mathematics departments. This could explore the transferability of the research approach reported in this study to the school setting and help to define further the nature of the resources, including mentor support, required to bring about school-wide implementation of TI-Nspire™ technology within the English school setting.

7.5.3

Whilst this study provided evidence of increased assessment opportunities for both teachers and learners, a more focussed study could explore the nature of this assessment opportunity to include the design of appropriate assessment tasks for different areas of the curriculum and ages of learners. The advent of a wireless classroom solution for TI-Nspire™ provides the context opportunity for a systematic longitudinal study to track the mathematical development of selected cohorts of students through their responses to rich exploratory TI-Nspire™ tasks.

7.5.4

This study did not elicit robust evidence about the student ownership model for the TI-Nspire™ within an English schools setting. As the level of teacher expertise with TI-Nspire™ increases it will be possible to research how the student ownership model supports students' mathematical learning. An alternative setting for this study could be by adopting a more "bottom-up" approach in a less "high stakes" setting, such as with a Year 12 class opting to study a free standing mathematics qualification (FSMQ) which requires students to use technology.

7.5.5

The United Kingdom STEM agenda (Her Majesty's Treasury 2004) is promoting cross curricular approaches to the learning of science, technology, engineering and mathematics in schools. As a comprehensive set of data logging probes for TI-Nspire™ become available, there is an opportunity to research how mathematics teachers can work collaboratively with their science and technology colleagues to promote cross-curricular approaches to solving problems generated from real-life situations.

7.5.6

Finally, an international study, developed to examine how the integration of TI-Nspire™ technology is implemented in different countries, either to contrast approaches to the curriculum or the models for teachers' professional development would significantly contribute to the knowledge base in these areas.

8 Table of figures

9 Table of Tables

10 Glossary

BECTa	British Educational Communications and Technology Agency
CPD	Continuing Professional Development (for teachers)
DfES	Department for Education and Skills
GCSE	General Certificate of Secondary Education (normally taken at the end of KS4)
ICT	Information and Communications Technology
KS3	Key Stage 3 (11 – 14 years)
KS4	Key Stage 4 (14 – 16 years)
NC	National Curriculum
NCETM	National Centre for the Excellence in Teaching Mathematics
OSFTED	Office for Standards in Education
SAT	Standard Assessment Test (normally taken at the end of KS3)
SEN	Special Educational Needs
SMILE	Secondary Mathematics Independent Learning Experience
SSAT	Specialist Schools and Academies Trust
STEM	Science, Technology, Engineering and Mathematics
TIMMS	Trends in International Mathematics and Science Study

11 Appendices

11.1 Research evaluation matrix

Major evaluation question	Sub question	Evaluation indicators	Methods of data collection and analysis (primary sources in black)
How does TI-Nspire™ impact on learning and teaching mathematics?	What are the features of effective classroom activities using TI-Nspire™?	Identification of effective classroom activities that TI-Nspire™ affords	Lesson components Teacher lesson evaluations Mentor lesson evaluation Student lesson evaluations Teacher reflections Teacher presentations
	How does TI-Nspire™ support learners to achieve mastery in mathematics concepts?	Identification of effective pedagogies that TI-Nspire™ affords	Lesson components Teacher lesson evaluations Mentor lesson evaluation Student lesson evaluations Student interview Teacher reflections Teacher questionnaire
	How are students motivated and engaged to learn mathematics using TI-Nspire™?	Identification of key features of TI-Nspire™ tasks which encourage students' motivation and engagement for the mathematics.	Teacher lesson evaluations Student lesson evaluations Student interview Student questionnaire Activities generated by students Mentor lesson evaluation Lesson components Teacher reflections
What is the nature of an effective professional development experience for teachers using TI-Nspire™?		Identification of key professional development activities which contribute to this	Teacher reflections Teacher lesson evaluations Lesson components Mentor evaluation

Table 11.1-1 Research evaluation matrix

11.2 Pilot schools' contextual data

Currently in England, 92% of state secondary schools are part of the Specialist Schools and Academies Trust (SSAT) network, which provides additional funding for schools who have successfully bid to develop an area of "specialism". All of the pilot schools are part of the SSAT network and their designated specialism is shown in Column 2. The percentages in Columns 5-7 refer to the nationally reported school data for students at age 14 and age 16 for 2007 as verified by the Department for Children Schools and Families.

1	2.	3.	4.	5.	6.	7.	8.
School (Code)	Specialism	Gender	Age range	Number on roll	L5+ KS3 Maths % *(2007)*	Level 2/GCSE 5 A* - C % *(2007)*	Level 2/GCSE 5 A* - C % incl English and maths *(2007)*
Bishop Brown School (BB)	Catholic Sports College	mixed	11 – 18	867	85	83	75
Coastway School (C)	Church of England Technology College	girls	12 – 16	1069	86	69	57
Greenmount School (G)	Specialist Arts College	mixed	11 – 16	1811	83	84	65
Hightrees School (H)	Technology College	boys	11 – 19	1402	93	83	67
Lime Street School (LS)	Humanities	mixed	11 – 19	1178	69	45	34
Pierview School (P)	Church of England Humanities	boys	12 – 16	714	77	58%	47
Stadium School (S)	Performing Arts Specialist College	mixed	11-18	1020	62	40	26

Table 11.2-1 Pilot schools' contextual data

A red figure above indicates below the national average and a green figure above the national average. The national average figures are shown below.

	KS3 % L5+ Maths *(2007)*	Level 2 (GCSE % 5 A* - C) *(2007)*	Level 2 (GCSE % 5 A* - C) including Maths *(2007)*
National average	76	62.0	46.7

In English secondary schools, the contextual background of pupils in the school is only reported through the descriptive text at the beginning of the school's Ofsted report and the percentage of pupils in the school deemed by the schools' own monitoring to have special educational needs, classified as School Action and School Action Plus.

School	Most recent Ofsted descriptor of the school	Percentage of pupils on roll with SEN with statements or supported at School Action Plus (2007 data)	Percentage of pupils on roll with SEN with statements or supported at School Action (2007 data)
Bishop Brown School	This is an oversubscribed specialist sports college, with a second specialist subject of geography. Students transfer mainly from a family of Catholic primary schools over a very wide area. The proportion of students who are eligible for free school meals is below average. Slightly less than 10% of the students come from minority ethnic groups and the proportion whose first language is believed not to be English is well below the national average. The percentage of students with learning difficulties and/or disabilities is below average, as is the proportion with a statement of special educational needs. (2007)	4.6	3.3
Coastway School	This is a large and oversubscribed Church of England Voluntary Controlled school. Most girls enter aged 12 into Year 8, with average levels of attainment. Nearly a third of students in each year group gains admission to the school on regular church attendance criteria. The diocese plays an advisory role in matters relating to collective worship and some aspects of curriculum provision. Most students are of White British heritage with English as their first language. (2007)	5.7	4.6
Greenmount School	The school is heavily over-subscribed. Few pupils come from minority ethnic backgrounds and very few do not speak English as their first language. The number of pupils entitled to free school meals is low. The proportion of pupils with learning difficulties and disabilities is similar to the national average but for pupils with a statement of special educational need it is low. (2006)	2.3	12.6
Hightrees School	The majority of the students come from White heritage backgrounds, although there are small numbers from Mixed, Asian, Black, Chinese and other backgrounds. The percentage of students whose first language is not English is low and only four students are at an early stage in learning English as an additional language. The percentage of pupils having learning difficulties and disabilities is broadly average. The current free school meals entitlement is below the national average. Students come from a range of social and economic backgrounds although the surrounding areas are generally more advantaged than average. The school population is relatively settled, with fewer students joining after Year 7 than the national average. The school is comprehensive in a borough that operates a selective system. (2007)	6.3	7.6

School	Most recent Ofsted descriptor of the school	Percentage of pupils on roll with SEN with statements or supported at School Action Plus (2007 data)	Percentage of pupils on roll with SEN with statements or supported at School Action (2007 data)
Lime Street School	This is a voluntary controlled school, with a long association with the Worshipful Company of Shipwrights. Students come from a wide range of heritage backgrounds. Just under a half is from White backgrounds and a further third from Asian backgrounds, largely Bangladeshi. Black, Chinese and other backgrounds are also represented. The percentage of students whose home language is not English (46.8 per cent) is very high, and 20 of these students are at an early stage in learning English. Students come from a range of social and economic backgrounds, but the above figures and those for the surrounding area confirm that many students come from backgrounds with a high level of disadvantage. A higher than average number of students join and leave the school at other than the usual times. (2004)	11.5	16
Pierview School	The number of students on roll has increased by about one third since the last inspection. Over 95% of students are of White British heritage. The proportion of students with learning difficulties or disabilities is similar to the national average. (2007)	8.7	8.5
Stadium School	The school, a specialist school for performing arts, is situated in the centre of *town name* and serves a diverse area with above average social and economic deprivation. About one third of students are White British, one quarter are from Pakistani backgrounds and nearly one eighth are from Caribbean backgrounds. Smaller numbers are from Bangladeshi and African backgrounds. One in ten students is at an early stage of acquiring English language. About one in seven students have learning difficulties. (2006)	5.2	9.9

Table 11.2-2 Pilot schools' contextual settings

11.3 Timeline of key project activities.

May-June 2007   Selection of schools and finalising project agreements

July 2007   First 2-day (residential) project meeting

                        Distribution of TI loan equipment to schools

                        Development of early TI-Nspire™ activities

Oct 2007   Second 2-day (residential) project meeting

                        Presentations of early classroom work by teachers

                        Revisions to early TI-Nspire™ activities

        Software upgrade

Jan 2008   Third project meeting (2 days)

                        Presentations of classroom work by teachers

                        Revisions to exemplar TI-Nspire™ activities

        Launching of TI-Nspire™ Activities Exchange

March 2008   Online questionnaires for pilot teachers and students

April 2008   Fourth project meeting (1 day)

        Final TI-Nspire™ lessons submitted

11.4 Pilot schools' existing ICT resources.

Each school was asked to report the range of software and hardware to which the mathematics department currently had access in the school year 2007-8. The responses are summarised below.

School	Existing ICT software resources for mathematics	Existing access to ICT resources
Bishop Brown School	Omnigraph Geometer's' Sketchpad MSW Logo Excel Subscription to the MyMaths.co.uk website.	All of the students in the school lease a laptop computer which they use in school and at home. Interactive whiteboards in all mathematics classrooms
Coastway School	TI Graphics Calculators The Geometer's Sketchpad Omnigraph Smile MSW logo Boardworks Cabri 3D Excel Subscription to the MyMaths.co.uk website.	Suite of 15 computers dedicated for use by the mathematics department. Access to these is timetabled such that all mathematics teachers have opportunity to use the suite with each class once a fortnight. The project teachers chose not to install the TI-Nspire™ software onto these computers during the project. Interactive whiteboards in all mathematics classrooms
Greenmount School	Trinity Maths Edexcel ExamWizard for GCSE TestBase Key Stage 3 Maths Ten Quick Questions Pro Boardworks Maths PowerPoint Boardworks Maths Toolkit Primary Games Volumes 1, 2 , 3 and 4 Geometer's Sketchpad Maths4real video clips Graphical calculators (TI 82/83) TI SmartView TI-Nspire Problem Pictures Subscription to Mymaths.co.uk website	Interactive whiteboards in all except one mathematics classroom (which has a data projector only). Department has a booking system for its own set of 23 laptop computers. Teachers choose when to book classes to use the school's ICT suites, where available.
Hightrees School	Autograph Excel HEADSTART Subscription to the MyMaths.co.uk website. SAM learning	Suite of 30 computers dedicated for use by the mathematics department. The project teachers chose not to install the TI-Nspire™ software onto these computers during the project.
Lime Street School	Excel Cabri-geometry Autograph Subscription to the MyMaths.co.uk website Mathletics Boardworks Exams Bank Standard Unit Improving learning in mathematics resources	The department has an appointed ICT coordinator. We plan into our schemes of work when ICT resources are to be used. We also have one classroom equipped with 18 computers which is used by a booking system.
Pierview School	Geometer's' Sketchpad Subscription to the MyMaths.co.uk website. TI-84+ Graphic Calculators Chefren's pyramid	School uses an electronic booking system for the ICT suites and as many mathematics sets as is possible have at least one lesson per fortnight in an ICT room. Individual teachers then book additional access through the school system. Department has a booking system for the graphical calculators.

School	Existing ICT software resources for mathematics	Existing access to ICT resources
Stadium School	RM Maths Alive, (which includes The Geometer's Sketchpad) Excel The Virtual Textbook software ATM's Interactive Mathematics software. Subscription to the MyMaths.co.uk	Limited access to schools computer suites due to unclear availability. All classrooms have a desktop computer. Five out of the six classrooms have a data projector. One classroom has an interactive whiteboard.

Table 11.4-1 Pilot schools' existing ICT resources and access

11.5 Pilot schools' use of ICT: Ofsted evidence

External inspection of schools, carried out by Ofsted, report on the overall standards of teaching and learning across the school and, on occasion specifically mention the use of technology.

Relevant extracts from the pilot school's most recent reports are included below.

School	Inspection report
Bishop Brown School	'E-learning' is integral to the life of the school and enhances learning. (2007)
Coastway School	ICT is used extensively as a versatile tool for teaching and learning. (2007)
Greenmount School	Teachers make sure they keep their skills up to date by making full use of the new opportunities presented through new technology such as interactive white boards, computers and most interestingly of all, the virtual learning environment. (2006)
Hightrees School	There is a planned training programme to encourage innovative ideas in teaching key areas of mathematics and to support teachers' use of ICT resources. (2001)
Lime Street School	Shared planning and the increasing use of ICT to demonstrate and model concepts are growing strengths within the department. (2004)
Pierview School	Some teaching also makes effective use of information and communication technology to enhance presentations and actively engage students. (2007)
Stadium School	The quality of teaching is satisfactory. Teachers know their subjects well, make good use of information and communication technology (ICT) in their teaching and gain the interest of students. (2006)

Table 11.5-1 Pilot schools' use of ICT (OFSTED)

11.6 Pilot schools' allocations of TI-Nspire™ resources.

School	TI-Nspire™ handhelds	TI-Nspire™ software	Organisation of resources
Bishop Brown School	2 *Teacher use only*	135	TI-Nspire™ software was installed on laptops belonging to all of the Year 7 students. The school used its VLE (*Moodle*) to share tns files.
Coastway School	30	22	The handhelds were shared by the two project teachers for use in class only.
Greenmount School	70	20	Handhelds were allocated individually to Year 9 pilot classes for use in and outside of the classroom.
Hightrees School	30	30	The handhelds were shared by the two project teachers. The devices were been numbered and allocated to named students for use in class only
Lime Street School	30	30	The handhelds were shared by the two project teachers. The devices were been numbered and allocated to named students for use in class only
Pierview School	30	30	The handhelds were shared by the two project teachers for use in class only.
Stadium School	40	10 *Teacher use only*	The handhelds were shared by the two project teachers. The devices were allocated to students randomly for use in class only.
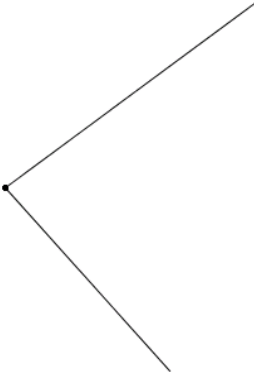
Table 11.6-1 Pilot schools' initial allocations of project resources

11.7 TI-Nspire^{TM} Lesson evaluation proforma (Part 1)

PART 1 From the lesson Angle bisectors [STP3]

Name: ██████████	Date: November 2007
School: ██████████	Class (and year): Year 8 set 1 of 6
Approx NC level: 6	Number of students: 30
Title: Angle bisectors – construction fan	Lesson code: STP3

During this mathematics lessons my students used:	**For the follow up mathematics homework my students used:**
(please circle) Only TI-*n*spire™ handheld device Only TI-*n*spire software on a PC **Handheld and Software TI-*n*spire** Neither	*(please circle)* Only TI-*n*spire handheld device Only TI-*n*spire software on a PC Handheld and Software TI-*n*spire **Neither**

What did you want the students to learn? I wanted the students to be able to construct angle bisectors using a ruler and compasses and understand why the construction works.
What activity did you choose (or develop)? The activity I developed was in several parts and lasts several lessons o   Work with the whole class, using dynamic geometry construction on board. Students work with the teacher in developing the construction 'from scratch' o   Students construct bisectors by hand using ruler and compasses o   Students construct bisectors on TI-*n*spire handhelds. They were not told about the *angle bisector* tool and instead used the circle, line segment and ray tools to construct the bisectors o   Using the TI-*n*spire handhelds, students make an 'angle bisector fan' This is an angle that is bisected into two angles, and these are each bisected into two smaller angles etc. When complete, the construction acts like a folding fan!
And what mathematical learning took place? Rather than simply construct an angle bisector (even correctly) I was able to work with the students on the reasons for the validity of the construction and prove that it worked.
How did you introduce the activity? See diagrams below, projected on to the screen in the lesson.

Here's an angle... we want to chop it exactly in half... any ideas? No... ok... well I'm going to try something...

I then create the following (deliberately incorrect) construction, talking through the procedure with my students as I do so.
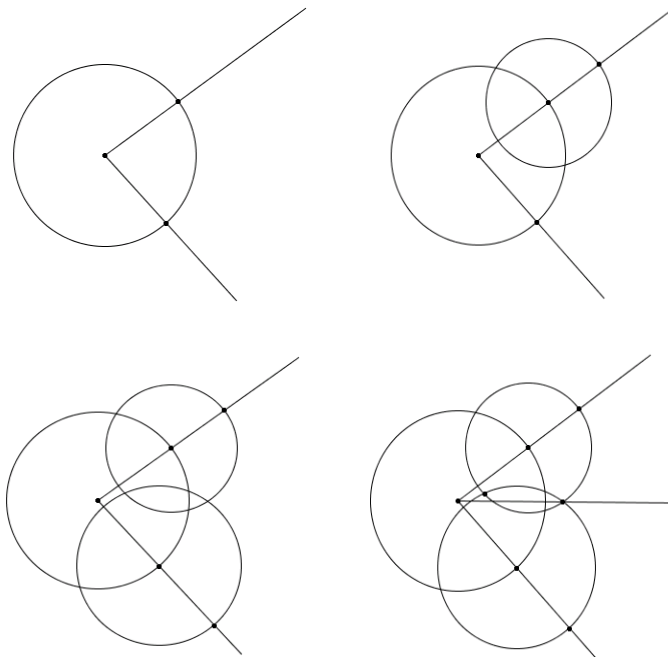
I then alter the size of one of the two circles that were drawn last. As I do so, the ray drawn in between the two 'arms' of the initial angles also moves. I ask students to tell me when the third ray is exactly half way (see diagram below). I do this several times and ask the students what is significant about the relative sizes of the circles when the third ray is exactly half way between the other two.
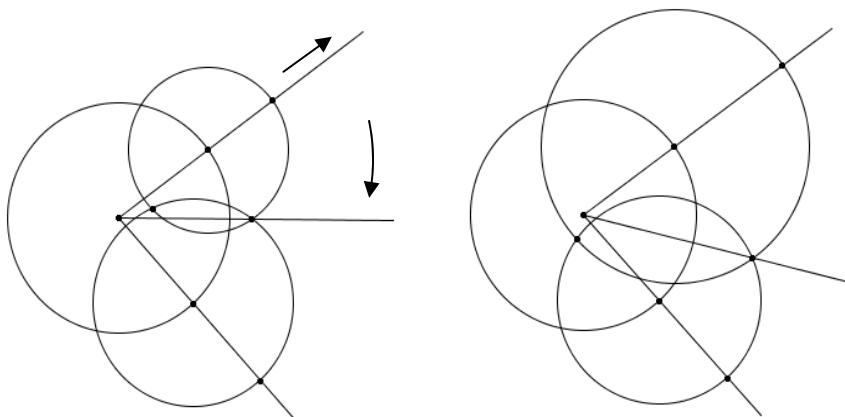
This is a whole class activity so far… and students call out when they see that the angle has been cut in half exactly. What follows is a discussion about what it is about having the last two circles of equal size that forces the angle to be cut in half exactly.
I now reconstruct the diagram, but this time demonstrate that I can force the two circles to be of equal size by drawing them so the centre and circumference of each of them are on the opposite points made by the first circle.
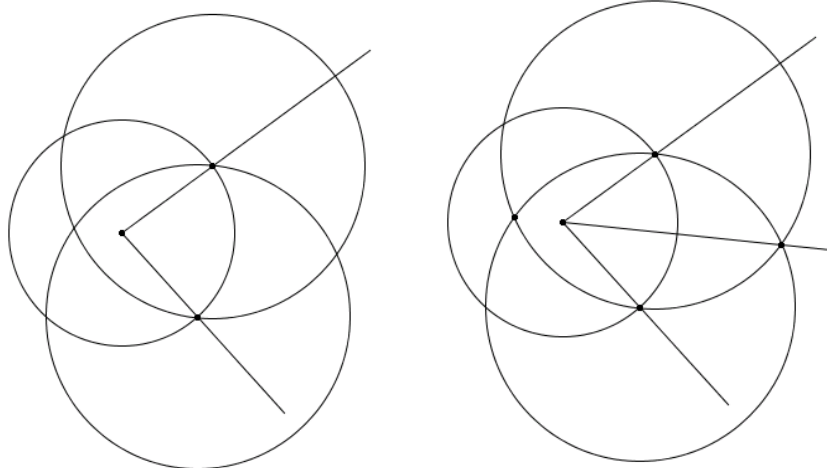
Students then constructed angle bisectors by hand using ruler and compasses on paper.

What were students' initial reactions/questions?

Students were interested in the construction... Most realised that two circles needed to be the same size for the angle to bisect correctly and wanted to know why.

Approximately how many of the students could develop strategies to fully pursue the activity with little or no guidance from you?

The activity for them at this stage was to construct an angle bisector by hand having seen the dynamic demonstration... Most students managed this fairly quickly. Some students needed help with using compasses.

What, if any, guidance did you have to give to the other students?
Please indicate how many students approximately needed additional guidance?

About 4 or 5 students out of the class needed to be reminded that the last two circles needed to be the same size as each other.

Give examples of the sort of interventions you made

You want these two circles to be the same size... How can you make sure that they are definitely going to be the same size?

How did the activity enable students to take more responsibility for their mathematical learning?

Rather than being given a set of instructions to follow, students made sense of a moving diagram in which the angle bisector exists as a special case. Students were able to understand what it is about the construction that makes it work.

Give a brief summary of the students' work/conclusions

Students created accurate angle bisectors. Interestingly, they drew circles not arcs in their books.

How did the idea influence further work?

In two further lessons, students created angle bisectors and perpendicular bisectors on their TI-*n*spire handhelds and went on to make a bisector fan (see below).
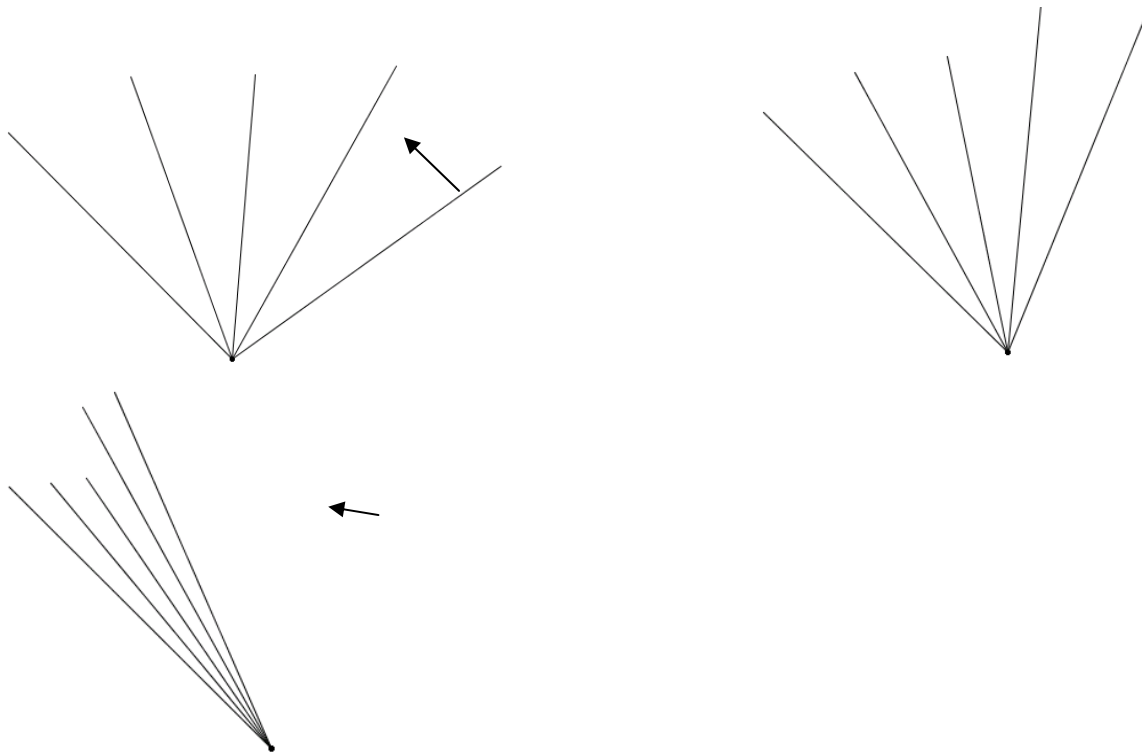
I was particularly impressed with how quickly students were able to construct these 'fans'... using circles and rays and hiding the construction lines.
What was significant about the TI-*n*spire construction that was that
- For it to 'work', i.e. for it to move dynamically, it had to be constructed correctly This means that the points of intersection needed to be constructed and the circles had to be the same size as each other... If each of these points is not thought about, the construction did not move dynamically.
- A handful of students in the class did not at first get this right... and this showed me as their teacher, which students in the class had understood the construction in previous lessons and which students had not understood the construction.

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

Probably all of it! As said above, I was impressed with
- How my demonstration using the software made the construction easier for the students to understand and therefore draw physically with compasses
- How quickly most students could make the 'fans' and how this required them to think about intersections etc.

What changes would you make?

In my initial whole class lesson working with the students on the construction of the angle bisector I would draw in some lines to measure the length of the radii to emphasise their equality.

Any other observations…?   pupils' comments…?   other   teachers'
comments…?

Student comments:

One student, describing "Why the method makes a perfect halfway" wrote: "Its to do
with the distance of the lines from the point its the same so that's why its possible to
draw a line exactly half way between the angle." *STP3/1*

Some students commented on the ability to interact with the images dynamically:

"…when you're doing it on the TI-*n*spire, you can move it around" *STP3/2*

"Using hand to draw is a bit easier but the advantage of using TI-*n*spire was that you
could move the drawn shape around so that was a bit better." *STP3/3*

Some students commented on how the TI-nspire made the mathematics more accessible
to   them:

"The TI-nspire was very helpful because you really couldn't go wrong and you could see
what you were doing." *STP3/4*

"Today I have learnt how to draw perpendicular bisects. I have learn't that pretty well
as the Tnspire was a great help because normally I am clumsy with drawing circles so it
was fun." *STP3/6*

Other students commented on enjoyment:

"It was very fun and simple. It was better than using my hand. I really enjoyed it."
STP3/5

In your view, did the use of TI-*n*spire enhance the mathematical understanding of the
students?

If yes, what evidence would you use to support this?

Yes, as stated above:

What was significant about the TI-*n*spire construction that was that

- For it to 'work', i.e. for it to move dynamically, it had to be constructed correctly
  This means that the points of intersection needed to be constructed and the
  circles had to be the same size as each other… If each of these points is not
  thought about, the construction did not move dynamically.
- A handful of students in the class did not at first get this right… and this showed
  me as their teacher, which students in the class had understood the construction
  in previous lessons and which students had not understood the construction.

11.8 TI-Nspire™ Lesson evaluation proforma (Part 2)

PART 2 Evaluation of students' mathematical activity (from the lesson Equations of parallel and perpendicular lines [PSH3(LEval-T)])

	Key process	Example
Representing	identify the mathematical aspects of the situation or problem	Needed to identify properties of straight line graphs
	choose between representations	
	simplify the situation or problem in order to represent it mathematically using appropriate variables, symbols, diagrams and models	Generalised from specific examples to a general rule. Ignored the intercept as it wasn't important.
	select mathematical information, methods and tools for use	
Analysing	make connections within mathematics	
	use knowledge of related problems	Y=mx+c
	visualise and work with dynamic images	Moved the straight line on the graph
	look for and examine patterns and classify	Plenary included a table of results to look for connections between the original equation and the perpendicular one.
	make and begin to justify conjectures and generalisations, considering special cases and counter examples	Y=x to y=-x led some pupils to believe y=2x would go to y=-2x. Y=2x to y=0.5x led some pupils to believe y=5x would go to y=5/4x (noticed divide by 4)
	explore the effects of varying values and look for invariance	Tried different values for gradient
	take account of feedback and learn from mistakes	Investigation style – trial and improvement
	work logically towards results and solutions, recognising the impact of constraints and assumptions	
	appreciate that there are a number of different techniques that can be used to analyse a situation	
	reason inductively and deduce	
Use appropriate mathematical procedures	make accurate mathematical diagrams, graphs and constructions on paper and on screen	Graphs on screen, measured angles
	calculate accurately, using a calculator when appropriate	
	manipulate numbers, algebraic expressions and equations and apply routine algorithms	
	use accurate notation, including correct syntax when using ICT	Discussion about f(x)= and y=
	record methods, solutions and conclusions	Recorded conclusions on handheld and in exercise books. Saved files on handheld.
	estimate, approximate and check working	
Interpreting and evaluating	form convincing arguments based on findings and make general statements	Pupils were asked to convince their partner and/or the teacher
	consider the assumptions made and the appropriateness and accuracy of results and conclusions	Measurements not always exact e.g. 90.34...° between y=2x and y=-0.49x
	be aware of strength of empirical evidence and appreciate the difference between evidence and proof	Measured the angle to show it was perpendicular, made general statements
	look at data to find patterns and exceptions	
	relate findings to the original context, identifying whether they support or refute conjectures	
	engage with someone else's mathematical reasoning in the context of a problem or particular situation	Discussion between pupils, some chose to work together in pairs on just one of their handhelds at various points within the lesson.
	consider whether alternative strategies may have helped or been better	

	Key process	Example
Communicating and reflecting	communicate findings in a range of forms	Function form and graphs. Discussed and then formalised findings in written form.
	engage in mathematical discussion of results	
	consider the elegance and efficiency of alternative solutions	
	look for equivalence in relation to both the different approaches to the problem and different problems with similar structures	
	make connections between the current situation and outcomes, and ones they have met before	Y=mx+c, connected rules for parallel and perpendicular lines (focus on gradient).

Adapted from QCA (2007) Draft Programme of Study: Mathematics (Key Stage 3)

11.9 Five dimensions and core features of successful mathematics classrooms

Dimensions	Core features
Nature of classroom tasks	Make mathematics problematic Connect with where students are Leave behind something of mathematical value
Role of the teacher	Select the tasks with goals in mind Share essential information Establish classroom culture
Social culture of the classroom	Ideas and methods are valued Students choose and share their methods; Mistakes are learning sites for everyone; Correctness resides in mathematical argument.
Mathematical tools as learning supports	Meaning for tools must be constructed by each user Used with purpose – to solve problems Used for recording, communicating and thinking
Equality and accessibility	Tasks are accessible to all students Every student is heard Every student contributes

Table 11.9-1 Core features of the five dimensions of effective mathematics classrooms (Hiebert et al. 1997)

11.10 Evaluating TI-Nspire™ Lessons: Background information

Lesson title and code:

About your planning and preparation

If the TI-Nspire activity was pre-constructed for this lesson, outline the story of its development *i.e. did you work with colleagues and/or mentors?*	
If the TI-Nspire file was constructed as an outcome of the lesson, outline how you did this, or supported this to happen.	
On reflection, was the planning and preparation for this lesson sufficient? If not, how could you have improved on this?	

About the TI-Nspire™ activity itself

Did the TI-Nspire activity include linked multiple pages? If so, what specifically did you link? (be specific to the activity please).	
Did your TI-Nspire activity include curriculum content from more than one NC Attainment area? Which ones?	
Did the students add their own notes to the TI-Nspire page? How did you organise this?	

About your classroom management of the activity

If the TI-Nspire activity was pre-constructed for this lesson how did you distribute the activity to the students?	
And how did you review the students' TI-Nspire work at the end of the lesson?	

11.11 Brief descriptions of TI-Nspire™ lessons

Brief descriptions of the TI-Nspire™ lessons reported by the project teachers are summarised below. They are arranged alphabetically by lesson code. All lessons used the TI-Nspire™ handheld, with the exception of those marked with an asterisk, which used the TI-Nspire™ computer software.

Lesson code	Lesson title	Description of lesson activity
BBAK-JJ1	Four fours*	Students downloaded a pre-constructed .tns file from the school virtual learning environment to their laptop computers. They used the Calculator application to try to use four fours and any combination of operations, including brackets, to generate the numbers from one to a hundred. They recorded their results in the Spreadsheet application and used a Notes page to record their findings. Students continued the task for homework and uploaded their .tns files to the school virtual learning environment at the end of the lesson.
BBAK2	Percentage multipliers*	Students downloaded a pre-constructed .tns files from the school virtual learning environment to their laptop computers. Students solved some problems relating to comparing decimals and percentages in the Spreadsheet application and used a Calculator page to check for validity. In the second part of the lesson they used the Spreadsheet application to solve numerical problems relating to percentage increases and decreases of given amounts. The students uploaded their .tns files to the school virtual learning environment at the end of the lesson.
BBAK-JJ3	Investigating straight lines*	Students created a new .tns file and used the Graphs and Geometry application to explore equations of straight lines of the form y = mx + c by varying m and c. They were encouraged to split their page and write about their observations using the Notes application. Students uploaded their .tns files to the school virtual learning environment at the end of the lesson.
BBAK-JJ4	Exploring angles*	Students downloaded a pre-constructed .tns file from the school virtual learning environment to their laptop computers. They measured the interior angles of several triangles using the Graphs and Geometry application. They did not drag any of the vertices. They entered angle measurements manually into a Spreadsheet page and commented on their findings using a Notes page. Students uploaded their .tns files to the school virtual learning environment at the end of the lesson.

Lesson code	Lesson title	Description of lesson activity
BBAK-JJ5	Comparing box plots*	Students downloaded a pre-constructed .tns from the school virtual learning environment to their laptop computers. They used a simple data set in the Spreadsheet application and used the defined functions mean and median to calculate these values. Some students also used formulae to calculate the range. They then inserted at Data and Statistics page and drew Box plots of the data to make comparative statements. Students uploaded their .tns files to the school virtual learning environment at the end of the lesson.
BBAK-JJ6	Weighing sweets*	Students downloaded a pre-constructed .tns from the school virtual learning environment to their laptop computers. They posed their own questions using a Notes page and then carried out a practical task. Students input data into the Spreadsheet application and observed the data plotted as a scatter plot in the Data and Statistics application. They used a movable line to model the algebraic link between the data sets. Students uploaded their .tns files to the school virtual learning environment at the end of the lesson.
BBJJ7	Angle bisectors*	Students created a new .tns file and used the Graphs and Geometry application to explore the construction of angle bisectors leading to the construction of an "Angle fan". Students saved their TI-Nspire™ work. Students uploaded their .tns files to the school virtual learning environment at the end of the lesson.
BBAK8	Pi Day*	Students created a new .tns file and used the Graphs and Geometry application with a set of instructions to construct a circle with a diameter, measure its diameter and circumference and save them as variables. Students then opened a Spreadsheet page to perform automated data capture of the diameter and circumference. They then added a Data and Statistics page and produced a scatter plot of the diameter and circumference. They added a movable line to find the algebraic relationship between the variables. Students uploaded their .tns files to the school virtual learning environment at the end of the lesson.
BBAK-JJ9	Investigating quadrilaterals*	Students downloaded a pre-constructed .tns from the school virtual learning environment to their laptop computers. They opened a Graphs and Geometry page and followed a set of instructions in the Notes page to construct a rectangle. They then moved on to measure the interior angles and side lengths for a given set of quadrilaterals (square rhombus, parallelogram, trapezium, isosceles trapezium, kite and arrowhead). They were encouraged to drag the vertices and record what they noticed using the Notes application. Students uploaded their .tns files to the school virtual learning environment at the end of the lesson.

Lesson code	Lesson title	Description of lesson activity
BBAK-JJ10	Constructing equilateral triangles*	Students created a new .tns file and used the Graphs and Geometry application to explore how to construct an equilateral triangle using circles alongside making the same constructions using a straight edge compasses. Students uploaded their .tns files to the school virtual learning environment at the end of the lesson.
CEL1	Quadrilateral angles	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They measured the interior angles of several polygons using the Graphs and Geometry application. They did not drag any of the vertices. They entered angle measurements manually into a Spreadsheet page and commented on their findings using a Notes page.
CEL2	Triangle angles	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They measured the interior angles of several polygons using the Graphs and Geometry application. They did not drag any of the vertices. They entered angle measurements manually into a Spreadsheet page and commented on their findings using a Notes page.
CEL3	Intersecting lines	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They dragged various points to observe changes in angle properties using the Graphs and Geometry application and commented on their findings using a Notes page. Students saved their TI-Nspire™ work.
CEL4	All angles recap	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They reviewed the mathematics from the other reported TI-Nspire lessons (CEL1 Quadrilateral angles, CEL2 Triangle angles and CEL3 Intersecting lines) using the Graphs and Geometry application but using the drag facility to vary the angles and recorded their own comments using the Notes application. Students saved their TI-Nspire™ work.
CEL5	Perpendicular lines	Students created a new .tns file and used the Graphs and Geometry application to define a linear function and draw a freehand "perpendicular line". They used the angle measure facility to check their accuracy, dragged the geometric line until it was perpendicular and then generated parallel functions to this geometric line. They used a Notes page to record their findings. Students saved their TI-Nspire™ work.
CHS1 LSMF2 HAC1 PSH1 GRE1	Four fours	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They used the Calculator application to try to use four fours and any combination of operations, including brackets, to generate the numbers from one to a hundred. They recorded their results in the Spreadsheet application and used a Notes page to record their findings. Students saved their TI-Nspire™ work.

Lesson code	Lesson title	Description of lesson activity
CHS2	Triangle angles	Students opened a pre-constructed .tns file which was distributed to them during the lesson using the link cables. They measured the interior angles of several polygons using the Graphs and Geometry application. They did not drag any of the vertices. They entered angle measurements manually into a Spreadsheet page and commented on their findings using a Notes page. Students saved their TI-Nspire™ work.
CHS3	Dice	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They used a straight dice simulation in the Spreadsheet application to generate sixty dice throws and observe the frequency graph in the Data and Statistics application. They then opened a second .tns file which included loaded dice and tried to ascertain which dice were loaded. Students saved their TI-Nspire™ work.
CHS4	Intersecting lines	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They dragged various points to observe changes in angle properties using the Graphs and Geometry application and commented on their findings using a Notes page. Students saved their TI-Nspire™ work.
GAS1	Box plots comparison	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They used given sets in the Spreadsheet application to draw parallel box plots in the Data and Statistics application and compare sets of data. They recorded their comments using the Notes page. Students saved their TI-Nspire™ work.
GAS2	Vitruvian man	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They had previously collected a set of heights and arm spans sixty people, which had been entered into the Spreadsheet application. The students made and tested hypothesis by using the Data and Statistics application to draw scatter plots of specific data. They recorded their findings using the Notes application. Students saved their TI-Nspire™ work, which was reviewed by the teacher.
GAS-BA3	Weighing sweets	Students opened a pre-constructed .tns file which was distributed to them during the lesson using the link cables. They carried out a practical task and input data into the Spreadsheet application and observed the data plotted as a scatter plot in the Data and Statistics application. Students used a movable line to model the algebraic link between the data sets.
GAS-BA4	Introducing trigonometry	Students opened a pre-constructed .tns file which was distributed to them during the lesson using the link cables. They used the Graphs and Geometry application to measure the sides of given right-angled triangles and used a Calculator page to calculate various ratios. Groups of students focused on a different set of triangles and these groups were mixed up to support the class to generalise about trigonometric rations during the whole-class plenary.

Lesson code	Lesson title	Description of lesson activity
GAS5	Circles 1 and 2	Students created a new .tns file and inserted a split page with a Graphs and Geometry (Analytic window) alongside a Calculator page. They constructed a circle and an inscribed quadrilateral, measuring the four interior angles and saving the measurements explicitly as variables. They used the calculator page to check angle sums using the variable notation and made generalisations relating to their explorations. In the second lesson they explored the angle properties of a quadrilateral with three vertices on the circle's circumference and the fourth vertex positioned at the centre of the circle.
GRE2	Vitruvian man	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They had previously collected a set of heights and arm spans sixty people, which had been entered into the Spreadsheet application. The students made and tested hypothesis by using the Data and Statistics application to draw scatter plots of specific data. They recorded their findings using the Notes application. Students saved their TI-Nspire™ work, which was reviewed by the teacher.
HAC2	Temperature conversion	Students created a new .tns file and used a step by step set of instructions created by the teacher to open a Lists and Spreadsheet page and input a set of values to represent temperatures in Celsius and type the given formula (=a1/5X9-32) to generate a set of temperatures in Fahrenheit. Students then were instructed to insert a Graphs and Geometry page and told how to produce a scatter plot of temperatures in °F against °C. They were instructed to join the points by using the Attribute "Points are connected".
HAC3	Further Conversions	Students opened a pre-constructed .tns file which was distributed to them during the lesson using the link cables. They used task instructions written in the Notes pages to draw scatter plots of various conversion data using Graphs and Geometry pages. The students had to deduce the conversion relationships in order to generate the spreadsheet data and respond to questions within the Notes pages.
HAC4	Adding fractions	Students created a new .tns file and used the Calculator application to add fractions of three types (same denominators, co-prime denominators, any denominator). The students recorded their own generalisations in the Notes application. The students shared these during a whole class plenary mediated by the teacher with the support of the project mentor. Students saved their TI-Nspire™ work.
HAC5	Data Handling Project	Students chose whether to use TI-Nspire™ or Excel to carry out their GCSE Statistics Data Handling project.
HRG1	Standard Form	Students chose whether to use their TI-Nspire™ handheld to solve a series of problems which led to Standard Form notation.

Lesson code	Lesson title	Description of lesson activity
HRG2	Equations of Straight Line	Students created a new .tns file and used the Graphs and Geometry application to investigate equations which produce parallel lines or lines that go through a particular point on the y-axis. Students then tested their predictions for the position of some given linear functions.
HRG3	Data Handling Coursework	Students chose whether to use TI-Nspire™ or Excel to carry out their GCSE Statistics Data Handling project.
LSMF1	Digit sums	Students created a new .tns file and used the Calculator application to try to find some two digit numbers which were a multiple of the sum of the two digits. Students recorded their findings in their exercise books.
LSMF3	Trial and Improvement	Students created a new .tns file and used the Calculator application and defined a given quadratic function and then substituted values of x to evaluate the function in order to find the solutions of the equation. They then used function notation to generate values and made this more efficient by using the Spreadsheet. Students recorded their findings in their exercise books.
LSMF5	Circles and Pi	Students created a new .tns file and the Graphs and Geometry application and used a step by step set of instructions prepared by the mentor to construct a circle with a diameter, measure its properties and save them as variables. Students then opened a Spreadsheet page to perform a data capture of the radius, diameter, circumference and area. They then added a Data and Statistics page and produced a scatter plot of the diameter and circumference.
LSSM1	Digit sums	Students created a new .tns file and used the Calculator application to try to find some two digit numbers which were a multiple of the sum of the two digits. Students recorded their findings in their exercise books.
LSSM2	Trial and Improvement	Students created a new .tns file and used the Calculator application and defined a given quadratic function and then substituted values of x to evaluate the function in order to find the solutions of the equation. Students then used a Spreadsheet page to automate the process and observed the scatter plot of the values of x and f(x). Students recorded their findings in their exercise books.
LSSM3	Mystery factors	Students created a new .tns file and used the Calculator application to explore the outcomes of inputting GCD(n:N) to explore highest common factor and LCM(n:N) to explore lowest common multiple. Students recorded their findings in their exercise books.
PCT2	Reflection	Students created a new .tns file and used the Graphs and Geometry application to construct a freehand 2-D shape and reflect it in both axes. They then defined the linear functions y=x and y=-x and reflect the shape in these lines to produce a Rangoli pattern. They then deformed their original shape by dragging vertices and observed the resulting transformations.

Lesson code	Lesson title	Description of lesson activity
PCT3	Quadrilateral angles	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They measured the interior angles of several polygons using the Graphs and Geometry application. They did not drag any of the vertices. They entered angle measurements manually into a Spreadsheet page and commented on their findings using a Notes page.
PCT3	Triangle angles	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They measured the interior angles of several polygons using the Graphs and Geometry application. They did not drag any of the vertices. They entered angle measurements manually into a Spreadsheet page and commented on their findings using a Notes page.
PCT3	Intersecting lines	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They dragged various points to observe changes in angle properties using the Graphs and Geometry application and commented on their findings using a Notes page. Students saved their TI-Nspire™ work.
PCT4	Solving simultaneous equations (Linear and quadratic)	Students created a new .tns file and used the Graphs and Geometry application to define two functions and use the Construction menu to find the intersection points. They checked the values by substitution. They worked on an alternative algebraic approach to solving simultaneous equations during the whole-class plenary.
PCT5	Solving simultaneous equations (quadratic and circle)	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They followed instructions on the Notes page to plot a linear and a quadratic function in a Graphs and Geometry page. They then used the Construction menu to find the points of intersection checked the values by substitution. They worked on an alternative algebraic approach to solving simultaneous equations during the whole-class plenary.
PSH1	Rich Aunt problem	Students created a new .tns file and used the Spreadsheet application to model the results of four different investment options aver different lengths of time. They input formulae to the spreadsheet and used the fill down functionality to generate lists of data and answer a set of related questions.
PSH2	Angles in circles and tangents	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. They used a geometric figure in the Graphs and Geometry application to make generalisations about angle and line properties of a circle's radius and tangent.
PSH3	Equations of parallel and perpendicular lines	Students created a blank .tns file and used the Graphs and Geometry application to generate linear functions of parallel lines. They then explored how to generate perpendicular lines, by measuring the angle between them and adjusting it to 90 degrees by dragging. They made and tested conjectures about the gradients of pairs of perpendicular lines. During the plenary they collated their findings resulting in a generalisation.

Lesson code	Lesson title	Description of lesson activity
PSH4	Exponential growth and decay	Students used 25 real dice each to obtain data to simulate an exponential decay. The group's results were collated by the teacher using the Spreadsheet application and a Scatter plot of the results drawn in the Data and Statistics page. Students then worked on similar problems from a text book scheme, to model growth and decay problems and fitted algebraic functions to the data.
PSH5	Enlargements	Students opened a pre-constructed .tns file which was distributed to them during the lesson using the link cables. They worked in the Graphs and Geometry application to enlarge a given shape by changing the scale factor using integer values. Students observed the resulting perimeter and area measurements and entered these into a Spreadsheet application. The teacher led a whole class plenary to discuss findings. The teacher did not review the students' TI-Nspire^{TM} files.
SJK1	Prime factorisation	Students created a new .tns file and used the Factor () command within the Calculator application to explore different inputs and outputs to encourage generalisation. Students recorded their work on a worksheet prepared by the teacher.
SJK2	Polygon angles	Students opened a pre-constructed .tns file which was distributed to students during the lesson using the link cables. They measured the interior angles of polygons using the Graphs and Geometry application. They summed the angles using the Calculator page and recorded their findings in their exercise books.
SJK3	n^{th} terms of sequences	Students created a new .tns file and used the Sequence command within the Calculator application to generate different sequences and explore the output. Students recorded their work on a worksheet prepared by the teacher.
SJK4	Straight line graphs	Students created a new .tns file and used the Graphs and Geometry application to explore varying the gradient and intercept for a linear function of the form $f(x) = mx+c$. Students recorded their findings in their exercise books.
SJK5	Scatter graphs	Students created a new .tns file and used the Spreadsheet application to enter a given set of data and produce scatter plots within the Data and statistics application. Students recorded their findings on an accompanying worksheet and were taught how to identify correlation relationships.
STP1	Prime factorisation	Students created a new .tns file and used the Factor () command within the Calculator application to explore different inputs and outputs to encourage generalisation. Students recorded their work in exercise books. Student self-evaluation supported the teacher assessment.

Lesson code	Lesson title	Description of lesson activity
STP2	Visual fractions	Students opened a pre-constructed .tns file which had already been loaded onto the handhelds by the teacher. It used a dynamic microworld to explore adding and subtracting fractions to encourage generalisation. Students recorded their work in exercise books.
STP3	Angle bisectors	Students created a new .tns file and used the Graphs and Geometry application to explore the construction of angle bisectors leading to the construction of an angle fan. Students saved their TI-Nspire[TM] work.
STP4	Circle circumferences	Students created a new .tns file and used the Graphs and Geometry application to construct a dynamic circle, measure its properties and tabulate the data in their exercise books. They then used the Calculator application to find the ratio of circumference:diameter and discussed their findings as a class. Students saved their TI-Nspire[TM] work.
STP5	Enlargements	Students created a new .tns file and used the Graphs and Geometry application to construct shapes, enlarge them and vary the centre of enlargement and position. Students saved their TI-Nspire[TM] work.

Table 11.11-1 Descriptions of individual TI-Nspire[TM] lessons organised alphabetically by lesson code

The following TI-Nspire[TM] activities devised by those involved in the project are available from the TI-Nspire[TM] Activities Exchange at: http://education.ti.com/educationportal/sites/UK/nonProductMulti/activities.html

Four fours   Trial and improvement   Compare box plots.

11.12   Analysis of TI-Nspire™ lessons

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

Teachers reported the title of their lesson, the students' year group (1), the main National Curriculum topic the lesson aimed to cover (2) and the estimated attainment level of the students (3). Each lesson was then evaluated by the research team and classified according to the TI-Nspire™ applications utilised (4) and an interpretation of the nature of this use. This is indicated by the grey shading in the table below. For example, whether the .tns file included more than one application (5) and if the lesson required the distribution of a pre-constructed .tns file (6). If the lesson involved the use of linked multiple representations, if this use was implicit in the choice of functionality, the block was shaded grey, whereas if the use was explicit in that teachers and or students actively linked variables, the cell was shaded black.

| Lesson code | Date taught | Lesson title (shading indicates it was developed collaboratively) | 1. Year group of pupils | 2. National Curriculum topic | 3. National Curriculum Level | 4. TI-Nspire™ application utilised | | | | | | 5. Incorporated multiple applications | 6. Used a pre-constructed .tns file | 7. Incorporated linked multiple representations |
						Calculator	Graphs and **Geometry**[8]	**Graphs** and Geometry[6]	Lists and Spreadsheet	Notes	Data and statistics			
BBAK-JJ1	**Sep-07**	Four fours	7	2	6							▨	▨	
STP1	**Sep-07**	Prime factorisation	8	2	6	▨								
CEL1	**Sep-07**	Quadrilateral angles	8	3	4		▨		▨			▨		
CHS1	**Sep-07**	Four fours	8	2	5-6	▨			▨			▨		
CHS2	**Sep-07**	Triangle angles	8	3	5-6		▨		▨			▨		
HAC1	**Sep-07**	Four fours	8	2	7	▨			▨			▨		
PCT1	**Sep-07**	Four fours	8	2	4-6		▨		▨			▨		
PCT3	**Sep-07**	Angles lessons	8	3	3-5		▨		▨			▨		

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[8] The bold text indicates whether this application was used predominantly as a graphing environment or a geometry environment.

Lesson code	Date taught	Lesson title (shading indicates it was developed collaboratively)	1. Year group of pupils	2. National Curriculum topic	3. National Curriculum Level	4. TI-Nspire™ application utilised						5. Incorporated multiple applications	6. Used a pre-constructed .tns file	7. Incorporated linked multiple representations
						Calculator	Graphs and Geometry[8]	Graphs and Geometry[6]	Lists and Spreadsheet	Notes	Data and statistics			
SJK1	Sep-07	Prime factorisation	9	2	6	▓								
SJK3	Sep-07	nth terms of sequences	9	2	6	▓								
LSSM1	Sep-07	Sums of sequences	9	2	6				▓	▓		▓		
LSMF1	Sep-07	Digit sums	9	3	5	▓								
LSMF2	Sep-07	Four fours	9	2	5				▓	▓		▓		
CEL2	Oct-07	Triangle angles	8	3	4		▓							
CHS4	Oct-07	Intersecting lines	8	3	5		drag			▓		▓		
HAC2	Oct-07	Temperature conversion	8	2	6-7		▓		▓			▓		▓
HAC3	Oct-07	Further Conversion	8	2	6-7				▓			▓		▓
PSH1	Oct-07	Rich Aunt problem	8	2	4-5				▓					
LSSM2	Oct-07	Trial and improvement	9	3	5	▓			▓		▓	▓		■
LSMF3	Oct-07	Trial and improvement	9	3	5	▓			▓					
GAS1	Oct-07	Box plots comparisons	9	4	7					▓	▓	▓	▓	▓
BBAK-JJ2	Nov-07	Percentage multipliers	7	2	6	▓			▓			▓		
BBAK-JJ5	Nov-07	Comparing box plots	7	4	6				▓		▓	▓	▓	▓
STP2	Nov-07	Visual fractions	8	2	6		drag		▓			▓		■
STP3	Nov-07	Angle bisectors	8	3	6		drag							
CEL3	Nov-07	Intersecting lines	8	3	5		drag			▓		▓	▓	
CEL4	Nov-07	All angles recap	8	3	5		drag			▓	▓	▓	▓	

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Lesson code	Date taught	Lesson title (shading indicates it was developed collaboratively)	1. Year group of pupils	2. National Curriculum topic	3. National Curriculum Level	4. TI-Nspire™ application utilised						5. Incorporated multiple applications	6. Used a pre-constructed .tns file	7. Incorporated linked multiple representations
						Calculator	Graphs and Geometry[8]	Graphs and Geometry[6]	Lists and Spreadsheet	Notes	Data and statistics			
HAC4	Nov-07	Adding fractions	8	2	7	■					■	■		
LSSM3	Nov-07	Mystery factors	9	2	5	■								
LSMF4	Nov-07	Mystery Factors	9	2	5	■								
GRE1	Nov-07	Four fours	9	2	6-7	■			■			■		
HRG1	Nov-07	Standard form	10	2	8	■								
HRG2	Nov-07	Straight line graphs	10	2	7		■		■			■		
HAC5	Nov-07	Data handling coursework	11	4	B-C				■					■
HRG3	Nov-07	Data handling coursework	11	4	7+				■					■
PCT2	Nov-07	Reflection	11	3	5-6		drag					■		
SJK2	Dec-07	Polygon angles	9	3	5	■	drag						■	
GAS2	Dec-07	Vitruvian man	9	4	B-C				■	■	■	■		■
GRE2	Dec-07	Vitruvian man	9	4	6-7				■	■	■	■		■
PCT3	Dec-07	Equations of parallel and perpendicular lines	10	2	A-A*		■	drag						■
PCT2	Dec-07	Angles in circles and tangents	11	3	D-G		drag						■	
BBAK-JJ3	Jan-08	Investigating straight lines	7	2	6			drag		■				
BBAK-JJ4	Jan-08	Exploring angles	7	3	6		■			■				
CHS3	Jan-08	Dice	8	4	5-6				■	■	■	■		■
LSMF5	Jan-08	Circles and Pi	9	3	5		drag		■					■
GAS-BA3	Jan-08	Weighing sweets	9	2	6				■	■			drag	■

Lesson code	Date taught	Lesson title (shading indicates it was developed collaboratively)	1. Year group of pupils	2. National Curriculum topic	3. National Curriculum Level	4. TI-Nspire™ application utilised						5. Incorporated multiple applications	6. Used a pre-constructed .tns file	7. Incorporated linked multiple representations
						Calculator	Graphs and Geometry[8]	Graphs and Geometry[6]	Lists and Spreadsheet	Notes	Data and statistics			
PSH4	Jan-08	Exponential growth and decay	10	4	A-A*									
BBAK-JJ6	Feb-08	Weighing sweets	7	2	6							drag		
STP4	Feb-08	Circle circumferences	9	3	6		drag							
GAS-BA4	Feb-08	Introducing trigonometry	9	3	6-7		drag							
GAS5	Feb-08	Circles 1 and 2	9	3	B		drag							
CEL5	Feb-08	Perpendicular lines	10	2	6		drag							
PCT4	Feb-08	Solving simultaneous equations	11	2	6-8									
PCT5	Feb-08	Solving simultaneous equations	11	2	6-8									
BBAK-JJ10	Mar-08	Constructing equilateral triangles	7	3	6									
BBJJ9	Mar-08	Investigating quadrilaterals	7	3	6		drag							
BBAK8	Mar-08	Pi Day	7	3	6		drag							
BBJJ7	Mar-08	Angle bisectors	7	3	6		drag							
SJK4	Mar-08	Straight line graphs	9	2	5									
PSH5	Mar-08	Enlargements	10	3	A-A*		drag							
STP5	Apr-08	Enlargements	8	3	6		drag							
SJK5	Apr-08	Scattergraphs	9	4	5									

Table 11.12-1 Analysis of TI-Nspire™ lessons arranged chronologically

11.13 Summary of supporting evidence.

A summary of the research evidence for each of the sixty-one lessons on which the conclusions and recommendations are based is summarised in Table 11.13-1.

Lesson code	Lesson title	Lesson Plan (LessPlan)	Lesson Structure (LessStr)	Teacher's .tns file (tns-T)	Students' .tns files (tns-S)	Students' Task Sheet (Task-S)	TI-Nspire Help Sheet (Help)	Lesson Evaluation (Teacher) (LEVal-T)	Lesson Evaluation (Mentor) (LEVal-T)	Lesson Evaluation (Student) (LEVal-T)	Teachers ongoing reflection (Refl-T)	Teacher's Presentation (Pres-T)
BBAK-JJ1	Four fours	■		■				■		■		
BBAK-JJ2	Percentage multipliers				■			■	■			
BBAK-JJ3	Investigating straight lines		■		■			■		■		■
BBAK-JJ4	Exploring angles		■		■			■				
BBAK-JJ5	Comparing box plots		■		■					■		
BBAK-JJ6	Weighing sweets		■		■			■				
BBJJ7	Angle bisectors		■		■			■				■
BBAK8	Pi Day		■		■			■				■
BBJJ9	Investigating quadrilaterals		■		■			■		■		■
BBAK-JJ10	Constructing equilateral triangles		■		■			■		■		
CEL1	Quadrilateral angles	■	■					■		■	■	
CEL2	Triangle angles	■	■						■	■		
CEL3	Intersecting lines	■	■					■				
CEL4	All angles recap	■	■					■				
CEL5	Perpendicular lines	■	■					■			■	
CHS1	Four fours		■		■			■		■		
CHS2	Triangle angles		■					■				
CHS3	Dice		■		■			■				

Lesson code	Lesson title	Lesson Plan (LessPlan)	Lesson Structure (LessStr)	Teacher's .tns file (tns-T)	Students' .tns files (tns-S)	Students' Task Sheet (Task-S)	TI-Nspire Help Sheet (Help)	Lesson Evaluation (Teacher) (LEVal-T)	Lesson Evaluation (Mentor) (LEVal-T)	Lesson Evaluation (Student) (LEVal-T)	Teachers ongoing reflection (Refl-T)	Teacher's Presentation (Pres-T)
CHS4	Intersecting lines		X					X			X	
GAS1	Box plots comparisons			X				X		X		X
GAS2	Vitruvian man			X		X		X				X
GAS-BA3	Weighing sweets			X				X		X		
GAS-BA4	Introducing trigonometry			X				X		X		X
GAS5	Circles 1 and 2	X						X		X		
GRE1	Four fours			X				X				
GRE2	Vitruvian man			X				X		X		
HAC1	Four fours											X
HAC2	Temperature conversion			X				X			X	
HAC3	Further Conversion			X				X				
HAC4	Adding fractions				X			X	X			
HAC5	Data handling coursework			X				X				X
HRG1	Standard form							X			X	
HRG2	Straight line graphs											
HRG3	Data handling coursework				X							X
LSMF1	Digit sums	X	X					X	X		X	
LSMF2	Four fours			X								
LSMF3	Trial and improvement		X			X		X				
LSMF4	Mystery Factors		X			X		X				

Lesson code	Lesson title	Lesson Plan (LessPlan)	Lesson Structure (LessStr)	Teacher's .tns file (tns-T)	Students' .tns files (tns-S)	Students' Task Sheet (Task-S)	TI-Nspire Help Sheet (Help)	Lesson Evaluation (Teacher) (LEval-T)	Lesson Evaluation (Mentor) (LEval-T)	Lesson Evaluation (Student) (LEval-T)	Teachers ongoing reflection (Refl-T)	Teacher's Presentation (Pres-T)
LSMF5	Circles and Pi		X			X		X				
LSSM1	Sums of sequences		X		X			X				
LSSM2	Trial and improvement	X			X	X		X				X
LSSM3	Mystery factors					X		X				
PCT1	Four fours		X			X		X				
PCT2	Reflections							X				
PCT3	Angles lessons							X				
PCT4	Solving simultaneous equations 1							X				X
PCT5	Solving simultaneous equations 2	X						X	X			
PSH1	Rich Aunt problem		X					X	X			
PSH2	Circles and tangents			X				X				
PSH3	Parallel and perpendicular lines	X		X				X			X	X
PSH4	Exponential growth and decay	X		X				X			X	
PSH5	Enlargements	X		X				X			X	
SJK1	Prime factorisation							X			X	
SJK2	Polygon angles			X				X		X		
SJK3	nth terms of sequences					X		X			X	
SJK4	Straight line graphs							X			X	
SJK5	Scattergraphs					X		X				
STP1	Prime factorisation				X			X			X	

Lesson code	Lesson title	Lesson Plan (LessPlan)	Lesson Structure (LessStr)	Teacher's .tns file (tns-T)	Students' .tns files (tns-S)	Students' Task Sheet (Task-S)	TI-Nspire Help Sheet (Help)	Lesson Evaluation (Teacher) (LEVal-T)	Lesson Evaluation (Mentor) (LEVal-T)	Lesson Evaluation (Student) (LEVal-T)	Teachers ongoing reflection (Refl-T)	Teacher's Presentation (Pres-T)
STP2	Visual fractions			▓		▓		▓		▓		▓
STP3	Angle bisectors			▓				▓		▓		▓
STP4	Circle circumferences							▓			▓	▓
STP5	Enlargements			▓				▓			▓	

Table 11.13-1 Summary of research data arranged by individual teacher

11.14   Using TI-Nspire™ in the classroom: Discussion Task

The statements below were used to stimulate discussion between the pairs of teachers from the same schools at the final project meeting.

Students choose when to use TI-Nspire	Students construct files for themselves	Tasks are accessible to all students
Every student contributes to the lesson	TI-Nspire enables students to make connections	The task has clear aims and objectives
TI-Nspire is used to solve a problem	Students use TI-Nspire to record, communicate and think	TI-Nspire is used to generate discussion between students

11.15   Detailed task instructions: Trial and improvement

Create a new blank document and save it as: **trial**

Starter Activity

When is $x^2 + 7x + 5 = 0$

Try a couple of possibilities long hand e.g. $x = 10$, do $10 \times 10 + 7 \times 10 + 5$ get 175 no use!

How could improve on this process?

On a new calculator page define the function: $f(x) = x^2 + 7x + 5$

Try $f(10)$, then improve $f(5)$, try more.

Main Activity

Open a new Lists & spreadsheet page.

Type headings for columns A and B for the number to test and the outcome of the test, for example number in column A and test in column B.

(Use the **doughnut** to navigate to the cell next to the A, type the word number, the press **enter**. Press **menu/Actions/Resize** and use the **right doughnut** to increase the width of the column until you can read the whole word. Then press **enter** to confirm. Repeat for column B).

In cell B1 type the function as a spreadsheet formula: $=a1^2 + 7a1 + 5$

Choose **menu/Data/Fill Down**

Press **down doughnut** to create 10 copies of the formula (i.e. down to row 10) and press **enter**. (A 5 will appear in every cell … this is the value of f(0)!)

Now you are ready to start finding the roots by trial and improvement.
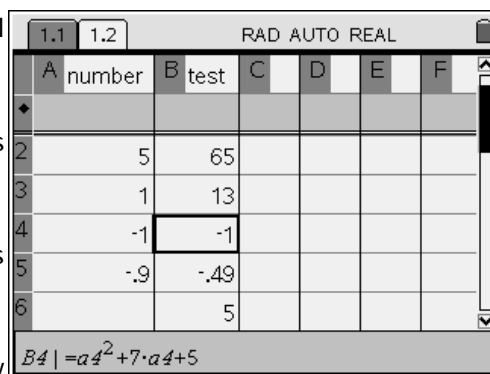
Navigate to cell A1 and try a first guess and press enter.

Now enter an improved guess in cell a2 and press enter.

Students should write down a commentary on how they are choosing their next 'guess' and get more specific as they get close to a solution. This set up gives them exactly 10 opportunities to improve.

Create a new Graphs & Geometry page.

Create a graph of the function:

Type $x^2 + 7x + 5$ into the entry line for f1(x) and press **enter**.

Interpret the solution from the first trial and improvement referring to the graph.

Notice that there is a second solution and notice roughly where it is.

Go back to the spreadsheet page. (**ctrl** + **left doughnut**)

Go to cell B10 and use fill down to create a further 10 spaces to find the second root.

Use trial and improvement to find the second root.

Students should describe how they choose the next 'guess' and describe the accuracy of their solutions.

Plenary

When both solutions are found to a suitable level of accuracy, review the function:

Create a new Data and Statistics page.

Use the doughnut to navigate to the bottom **click to add a variable** box. Click in it ensure the list called number is highlighted and press **enter**.

Now navigate to the **click to add a variable** box on the side. Click in it ensure the list called test is highlighted and press **enter**.

Discuss the shape of the graph and how it was created.

Use this discussion to review the solutions to roots of the function.
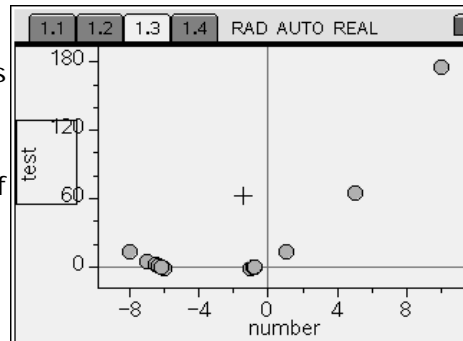
11.16 Exploiting the advanced functionality of TI-Nspire™ – Redesigning the "Triangle angles" task

Two alternative approaches to this task which exploit the advanced features of TI-Nspire™.

Scenario 1

In Figure 11.16-1 a single triangle has been constructed in the Graphs and Geometry application (Analytic view) and its interior angles measured to two decimal places and saved as variables A, B and C. In the Calculator application, the instantaneous values of angle A, B and C can be evaluated along with the sum of the three angles. By dragging any of the vertices A, B or C, a new situation is created.
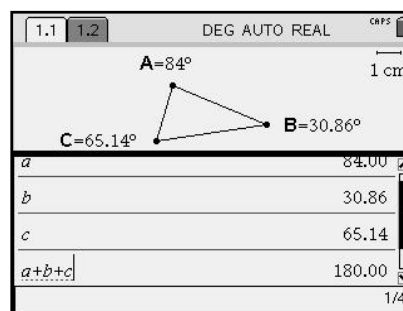

Figure 11.16-1 Interior angle sum of triangles: Geometry and Calculation applications

Scenario 2

In Figure 11.16-2, the same single triangle has been constructed in the Graphs and Geometry application (Analytic view) and its interior angles measured and saved as variables A, B and C.
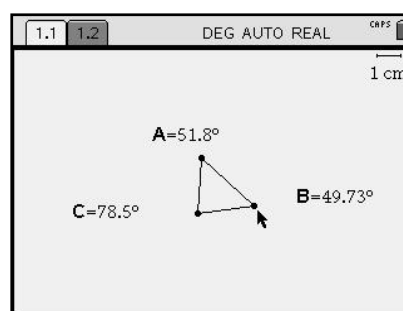

Figure 11.16-2 Interior angle sum of triangles: Geometry application

On the second page, the Spreadsheet application has been used to carry out an automated data capture of the previously defined variables, A, B and C, with the total of these three angles calculated in Column D.

As any vertex of the triangle is dragged on page 1, so the data is captured and displayed in the Spreadsheet application.
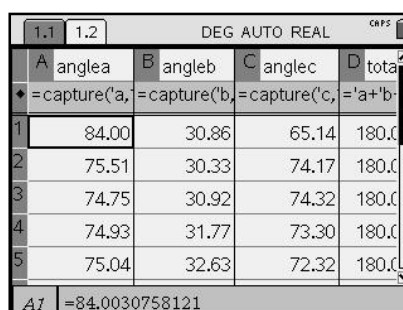

Figure 11.16-3 Interior angle sum of triangles: Spreadsheet application

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