QCA-RSS Centre Project
Handling Data and Statistics

Final Project Report

December 2006
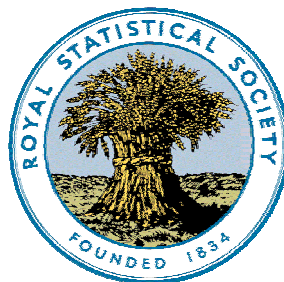
EXECUTIVE SUMMARY

This is the fourth and final report of the project. Three interim reports were submitted to the QCA in: May 2005; November 2005; and June 2006. The November 2005 report contained five recommendations that were based on the analysis of a nationwide survey of heads of mathematics, science and geography departments in English secondary schools. In this report we present a further six recommendations arising from the work carried out since January 2006, the first five recommendations were discussed in detail in the November 2005 report. For completeness initially we present the first five recommendations.

Recommendation 1 - The Curriculum

We recommend that the statistics and data handling content of the mathematics curriculum should be seeded through real world examples drawn from science, geography and other subjects but should be retained within the mathematics curriculum.

Recommendation 2 – Assessment

We recommend that a range of new ways for assessing the statistics and handling data coursework be trialled. All of these alternatives should be designed to occupy no more than a single week of class time. Of the suggested alternatives in the questionnaires, the in-depth interviews in schools have so far shown that teachers thought the field centre option was impractical. We will also consider other possible approaches.

Recommendation 3 – Continuing Professional Development (CPD)

We recommend that a programme of CPD be developed for Heads of Mathematics with particular regard to teaching how the problem solving approach (data handling cycle) can best be taught. This will also be necessary for Heads of Science and Geography if they are required to teach this material.

Recommendation 4 - Teaching Materials

We recommend that a comprehensive range of teaching materials be developed and made available to Heads of Mathematics to facilitate the teaching of all topics within the statistics and data handling content of the mathematics curriculum. These should be designed to use real data from other subject areas and should embrace the problem-solving approach.

Recommendation 5 – Trialling

We recommend that material for trialling in schools be based on the topics: handling data project; measures of location; measures of variation; regression and time series; and inference from data. The chosen topics should be explicitly taught through problem-solving.

The following six recommendations result from the work carried out by the project team since January 2006 acting on recommendations 4 and 5.

Recommendation 6 – Future Strategy for Teaching and Learning Statistics
We recommend that the QCA should promote the teaching and learning of statistics and handling data through the statistical problem solving approach.

Recommendation 7 – Resources for Teaching and Learning Statistics
We recommend that the QCA should promote the development of a database of resources containing examples of the use of the statistical problem solving approach which should be made available to school teachers. A common format for the resources, as exemplified by the resources developed and trialled by this project, should be used.

Recommendation 8 – Teacher Professional Development in Statistics
We recommend that the QCA should promote the development of online CPD resources designed to demonstrate the use of the resources in Recommendation 7 to school teachers. These should be developed in tandem with the teaching resources.

Recommendation 9 – Creating a Portfolio of Resources
We recommend that the QCA should give priority to the development of online CPD resources that will enable school teachers to take ownership of their CPD needs by facilitating the transformation of their own case studies and examples into further resources in the style of those in Recommendation 7.

Recommendation 10 – Development of Assessment
We recommend that the assessment of the problem solving approach, described as the Data Handling Cycle in the National Curriculum, should be undertaken by using, and further developing, the approach to this assessment developed by this project.

Recommendation 11 – Dissemination
We recommend that a national conference/workshop be organised by the QCA where teachers can learn about the resources and get involved with the creation of further ones in line with recommendations 9 and 10. This could be done under the auspices of the NCETM.

Contents

1 Introduction

This is the final report from the Royal Statistical Society Centre for Statistical Education (RSSCSE) on its project to investigate Statistics and Handling Data (S&HD) in the English national curriculum. In this we present the final results of trialling teaching and learning resources written using the problem solving approach to teaching S&HD in KS3 mathematics. In addition we provide a discussion of assessment regimes developed for the project resources.

The development of the teaching resources was informed by the feedback and recommendations made following the national survey of teacher views carried out in the latter part of 2005. The aim of the survey was to determine what areas of S&HD should be retained within the mathematics curriculum and what could be beneficially seeded through other subjects. Initially, the resources developed within the remit of this project were to be designed for teaching S&HD through real problems, within other subject areas.

Recommendation 1, arising from the survey, is that S&HD should remain within the mathematics curriculum but be taught through *real examples*, embedding statistical techniques within a problem solving approach. The materials that have been developed show how this can be done as well as covering particular areas of the curriculum identified as weaknesses by the survey. For more information about the interim report and recommendations made in November 2005 visit http://www.rsscse.org.uk/qca/outcomes.htm.

2 The Teaching and Learning Resources

2.1 Review of progress

The June 2006 report to the QCA provided an account of the design and first stage of trialling of the developed resources. It was decided that further resources developed for the project would have a common format and would be based on the RSSCSE/QCA web pages created for the first four problems. The following features were considered important and have been incorporated into a common template:

- Colour coding - used to reinforce the data handling cycle/ problem solving approach;
- Common symbols - used to reinforce the colour coding;
- Data collection used in activities is easy to reproduce in the classroom;
- Material is provided to assist the teacher in the initial discussion phase;
- Key questions are included to stimulate the interpret-and-discuss phase;
- The materials are designed to be relevant and engaging and motivate the staff to deliver;

Central to each resource is a PowerPoint presentation. This has teachers' notes embedded within it and is supported with other classroom materials. The resources are accompanied by continuing professional development (CPD) material for teachers in the form of an online training 'flash-player' facility designed to explain the use of the teaching resources. Appendix 1 contains a static copy of this training resource. It can also be viewed from the CD-Rom accompanying this report.

2.2 The initial resources

The first four resources use the problem solving approach illustrated in Figure 2.2.1
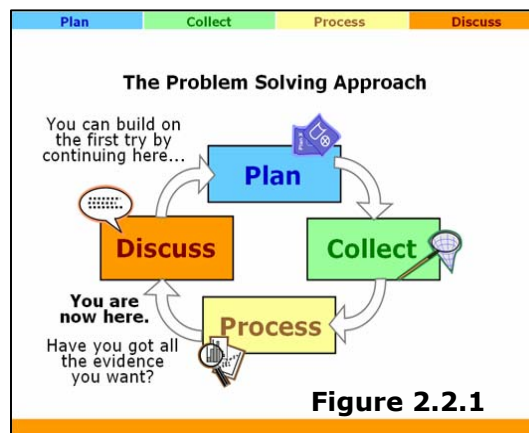
Figure 2.2.1

The slide shown in Figure 2.2.1 here punctuates each of the developed presentations. It is our belief that the four stages of the problem solving approach need to be rehearsed as each cycle of activities is completed and, from a learning perspective, students should be aware of where they are in the cycle: it is good practice to anticipate future stages and be reminded of how they arrived at the current stage.

Descriptions of the first four resources follow. All tasks use the problem solving approach (Figure 2.2.1) and are designed to take approximately 3 hours of teaching time.

1. ***How safe is your area?***
   This resource enables teachers to help pupils consider the problem of safety of an area for living in. It involves the use of primary and secondary data. Pupils plan to investigate how crime statistics and perceptions of crime are related, in and around their region. They consider a wide range of crime statistics and focus on those crimes that most interest them. They compare their own 'perceptions of crime' survey with actual figures for 2004/5 taken from the British Crime Survey. Figures have already been collated for different regions of the UK and data are available for the past 5 years.

2. ***Crime scene evidence.***
   This resource enables teachers to lead pupils through a crime investigation to help solve the problem of 'whodunnit?' A theft has occurred and the only clue to identify the culprit is a footprint. Pupils investigate how helpful the footprint may be in identifying the thief. They use averages as well as histograms and scatter diagrams to explore the likelihood of various suspects being the culprit.

3. ***Virtual reality gloves*.**
   This resource enables teachers to help pupils develop solutions to a particular problem; identifying demand for different designs of Virtual Reality Gloves. Pupils plan how they will collect and record information on 'handedness' and 'thumbedness' to help a manufacturer identify the possible demand for different designs. This is an exercise in data collection. It can be easily adapted to use a variety of discrete variable presentation methods and would ideally lend itself to pupils choosing how to represent data themselves and allows for a discussion of the suitability of their chosen method. It also illustrates how a single pass through the handling data cycle can, following suitable evaluation, lead to the need for a second, modified iteration of the cycle.

4. ***Where's worst?***
   This resource enables teachers to lead pupils through the problem of how to select areas of their school environment to improve. As a group they decide on the characteristics to use

to judge the environment using a technique from geography (Environmental Quality Indexing, EQI). Pupils collect data on their own school environment to help them choose the area for improvement. This involves a qualitative survey (EQI) and processing through the use of stem-and-leaf diagrams. The pupils' task is to produce a written report for the school council giving details and supporting evidence about the area they think should be improved.

These four resources were extensively trialled in schools and this process, together with the feedback obtained from teachers and students, was used to refine them further. Full details of the process involved in the selection of schools for the trials, the gathering of feedback from teachers and students and the analysis of the feedback can be found in the June 2006 report to the QCA.

2.3 Feedback on the resources

The feedback from teachers was obtained using an online flash-player facility. The initial feedback questionnaire was itself refined in the light of feedback from teachers participating in the first trial. A static version of this refined feedback questionnaire is contained in Appendix 2 and summarised here. The flash version is available on the accompanying CD-Rom. Questions are asked under the following four headings:

1. **Online guidance**
   The teachers were asked whether the online guidance materials were: clear; easy to use; written with an appropriate level of detail; helped the teacher understand the background of the material; made clear where the teacher could obtain help; and helped the teacher understand the problem solving approach.

2. **Teaching materials**
   The teachers were asked whether: the teaching materials were easy to access from the website; the teaching notes contained an appropriate level of detail; their presentation was clear; their structure was easy to use; their delivery options were suitable for use in the classroom; and the stated levels were appropriate.

3. **Effectiveness of materials**
   The teachers were asked whether: the suggested classroom time was appropriate; the context of the activity was relevant and engaging; the pupils enjoyed the work; the pupils were able to understand the tasks quickly; the pupil worksheet contained sufficient detail, were clearly structured and the structure was easy to use; they believed the materials had a positive effect on learning in the classroom; they would use the same materials again; they would use the same materials without any changes; they would use the same materials with older students; they would find similar resources useful for older students; and they would appreciate additional resources written in the same style.

4. **General comments**
   The final feedback question invited teachers to complete a free text response to suggest improvements, mistakes, omissions etc.

Additional feedback on the resources was obtained from the statistical education consultant James Nicholson (Durham University) who was asked to provide comments. His comments are included in Appendix 3.

At the end of the initial stage of the trialling of the materials changes were made in the light of the feedback received and a further stage of trialling of the revised resources was undertaken. The resulting feedback from the teachers is presented in the dotplots of Appendix 4.

2.4 Additional resources

After the format of the resources had been successfully trialled and adapted in the light of the feedback received, four additional resources were developed. This was done to ensure that a bank of materials, that provided examples of all of the topics identified in recommendation 5, are available on the project website. In a similar manner to the original resources, these resources are based within the problem solving approach and are intended to take around three hours of teaching time:

5. ***How far, fast and high?***
   This resource provides a structure for considering and investigating world records in athletics. It involves students handling data in order to answer questions or investigate a hypothesis. Pupils are encouraged to predict changes over time - by how much and how quickly are world records being broken in track and field events? Can we predict the likely world records this time next year? The materials cover two different approaches to data – testing a hypothesis – for example 'women are always slower than men' and using data to answer questions of interest – when was the last time the triple jump record was broken? How often is it broken? Can we predict when it will next be broken?

6. ***How old is your height?***
   This resource explores the use of data within the historical context of the Industrial revolution. In 1833 the first factory act was introduced to control the employment of children in factories. Inspectors were employed to enforce the act – to solve the problem of identifying a child's age. Pupils are encouraged to look at what the inspectors did and consider their data, thinking about its reliability and use their own data as well as data from *CensusAtSchool* to compare children's heights now and then. Optional material contained in the presentation leads pupils to consider spread in data and how a box and whisker plot can be a helpful graphical tool.

7. ***What's in your bowl?***
   This resource enables teachers to lead pupils through the problem of clear labelling of food to help make good dietary choices. The Consumers Association (Which?) and Food Standards Agency have suggested a traffic light system (good, fair & bad) to be printed on labels. Pupils investigate the content of breakfast cereals and apply the traffic light system to the results. Pupils are encouraged to look at the salt, fibre and sugar content of cereals according to either their popularity or by the type of cereal (i.e. rice, oat, corn or wheat). The pupils' task is to summarise their findings, based on average mass per 100g, and to apply the traffic light labelling system to see how different cereals rate. This work can involve a pupil questionnaire on popularity and collecting of actual data from packets obtained either from shops/supermarkets or online via manufacturers' websites.

8. ***World population***
   This resource enables teachers to lead pupils through an investigation into the size of the World's Population - how quickly is it increasing, where is it increasing the most and when might we reach our planet's limit. Through the use of the problem solving approach, writing and investigating hypotheses is introduced. There is optional material on primary and secondary data. Pupils will use line graphs to present data. The materials address issues such as reliability of data, use of estimation and the use of relatively simple mathematical models to represent a more complicated situation. There are two optional activities within the materials – the first familiarises pupils with general population figures and allows them to explore the wealth of data available on the Internet and the second uses sweets to form a simple model of population growth.

This second group of resources were sent to consultants for review and comment. Jo Walker, (Wycombe High School), was asked to review two; James Nicholson was asked to review the

remaining two; and Peter Holmes and Doreen Connor were asked to review all four. The consultants were asked to comment under the headings below, which correspond to the headings used within the feedback for the first set of materials:

- **Online guidance:** *e.g. clarity, ease of use*
- **Teaching materials:** *e.g. their structure, accompanying notes*
- **Effectiveness of materials:** *e.g. appropriateness, pupil relevance*
- **General comments:** *improvements, mistakes, omissions etc.*

A summary of the responses from these consultants is presented in Appendix 5.

A complete, interactive, set of the resources is included on the CD-Rom provided as part of this final report.

2.5 Flexibility of the resources

The resources have all been designed to fit a common template with a common colour coding for the different stages of the problem solving approach for the reasons stated in Section 2.1. It is the intention that the materials can be used according to the needs of the teacher. Experienced and confident colleagues may be less dependent on the accompanying notes whereas less confident and/or less experienced teachers may appreciate and utilise some or all of the support provided in the supporting documents. The resources have been deigned with the intention that, subject to the methods and techniques being appropriate to the nature of the variable(s) measured and the problem which is being solved, the problems could be adapted to include *any* of the S&HD methods and techniques from the National Curriculum.

The evidence from the trials and feedback from teachers is that these eight resources provide a successful platform for the teaching and learning of S&HD through the problem solving approach. They also have the potential to form the basis of a national database of similar resources for teaching and learning S&HD at all levels of the National Curriculum in mathematics at key stages 2, 3, 4 and 5. At the same time they meet the recommendation from the Smith report that S&HD should be taught *through* other subjects. Indeed the problem solving paradigm can be used to teach statistics at any level in many subjects.

2.6 Support for the problem solving approach

A university-level project took place in the early 1990s that was dedicated to creating material for teaching statistics through problem solving. The Statistical Education through Problem Solving (STEPS) computer-based learning modules were produced by a consortium of seven UK universities. See, for example, Bowman et al (1998). Application areas include Biology, Business, Geography and Psychology.

The statistical problem solving paradigm also appears in slightly different forms in several recent syllabuses in science, for example, at GCSE level in the new 21st Century Science specification. The Association of Science Education and King's College, London, ran a project to develop pupils' understanding of the *nature* of scientific activity and the relationship between data and scientific activities. As a result of this, Goldsworthy, Watson and Wood-Robinson (2000) wrote an excellent book called *Developing understanding in scientific enquiry.* This book provides a practical approach to developing thinking skills and strategies to guide activities to make the most of data collected.

In 2004 the American Statistical Association endorsed the reports from the Guidelines for Assessment and Instruction in Statistics Education (GAISE) project which advocate the active learning of statistics using real data and a problem solving approach. Rossman (2006) found that using the problem solving approach to the teaching of statistics is of great benefit to both

teachers and pupils. Groth (2006) also advocates shifting the teaching of statistics "…toward what can be called a more authentic approach that involves genuine problem solving and reasoning with data."

These discussions, the research evidence from the US, together with our experience and feedback from teachers and pupils in the UK lead us to make recommendation 6.

Recommendation 6 – Future Strategy for Teaching and Learning Statistics
We recommend that the QCA should promote the teaching and learning of statistics and handling data through the statistical problem solving approach.

In 2005, in their response to the Leitch Review on Skills, the Confederation of British Industry (CBI) discusses the different responsibilities of employer, employee and government and assert that:

> "…it is the joint responsibility of employers, individuals and government to ensure the UK workforce has the necessary skills competences to increase productivity:
>
> • government is responsible for the education and training of young people and should ensure they are employable. It should support organisations with little capacity to train and individuals with little opportunity to learn. It must ensure that education and publicly funded workforce training improves to meet both employers' and individuals' needs."

They continue to suggest that

> "A comprehensive action plan must ensure that:
>
> • the curriculum for 14-19 year old pupils delivers the basic skills of numeracy and literacy; a new basic skills strategy for 14-19 pupils is needed, fully integrated with the numeracy and literacy strategies for younger pupils. Employers would be happy to share their knowledge of what numeracy and literacy means in the workplace
> • best practice in the classroom is identified and implemented in all schools and colleges as part of a plan to improve the teaching of basic skills-tailored teacher training will be necessary to provide teachers with the appropriate competencies
> • students are fully aware of the need for basic skills in the workplace and the role these skills play in their future career development and success"

The problem solving approach provides a natural platform for the development of many of the 'functional mathematical skills' mentioned by the CBI and identified as essential for industry by the Techno-mathematical Literacies in the Workplace project being run at the Institute of Education[1] In addition the 'Plan' and 'Discuss' stages of the problem solving approach encourage the development of literacy skills through communication and the reporting of findings. These discussions lead us to recommendation 7.

Recommendation 7 - Resources for Teaching and Learning Statistics
We recommend that the QCA should promote the development of a database of resources containing examples of the use of the statistical problem solving approach - this should be made available to all school teachers. A common format for the resources, as exemplified by the resources developed and trialled by this project, should be used.

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[1] http://www.ioe.ac.uk/tlrp/technomaths

The feedback from teachers obtained during the trialling of the resources indicated that teachers valued the online instructional material and agreed that, together with the teachers' notes, it was helpful in both introducing the resources and in demonstrating the place of the problem solving approach in statistical thinking.

There is a growing consensus, driven by a concern for the future of the UK economy that the teaching of basic skills, including those developed and nurtured when teaching using the problem solving approach, must be the focus of renewed effort. The CBI recently undertook a survey of private sector employers, as well as conducting a series of case studies covering a cross section of employers, with the aim of investigating the use of literacy and mathematical skills in the workplace. The report sought employers' views on any shortfalls in the skills that they had experienced in their employees. The results are contained in 'Working on the Three Rs', Confederation of British Industry (2006)[2], and the following are those key conclusions from the report that either refer explicitly to techniques that are taught as part of the Ma4 curriculum or are implicitly learnt through the use of the problem solving approach.

- Reading and writing must be considered separately. They tend to be rolled up together and treated as one, but writing tends to pose much more of a problem. The ability to put together a piece of writing that conveys meaning clearly and accurately is an essential functional skill. The inability to put together a short coherent piece of writing has serious implications for those seeking work or thinking of changing jobs.
- Understanding and responding appropriately to oral communications are essential skills. Employees also need to be sufficiently articulate to be able to raise queries if the instructions are not clear to them, or to raise practical matters of concern that flow from the instruction.
- The ability to interpret and respond to quantitative data is a key part of modern working life
- Spotting errors and rogue figures is an important element of functional maths
- Some grasp of odds and probabilities forms part of mathematical literacy
- Functional skills are skills that have a practical purpose. It is important to boost awareness of their potential application, particularly key elements of mathematical literacy, in real and different contexts.

In addition to this, the CBI Business Summary on Education-business partnerships, published on 17th October 2006, observed that

> "Just over half (52%) of employers were dissatisfied with school leavers key employability skills such as communicating, team working and problem solving."

These reinforce Recommendation 7 and also support our view that, in addition to the need for the resources articulated in recommendation 7, there is an urgent need for CPD resources to assist teachers in the areas of weakness that were identified in our survey of heads of departments. It is clear that the successful teaching of statistical thinking through the problem solving approach is needed to provide a workforce with the necessary skills. It is our belief that courageous decisions at a national level will be needed to ensure that this happens.

Recommendation 8 - Teacher Professional Development in Statistics
We recommend that the QCA should promote the development of online CPD resources designed to demonstrate the use of the resources in Recommendation 7 to school teachers. These should be developed in tandem with the teaching resources.

The survey of department heads in English secondary schools demonstrated a clear perception, particularly among heads of mathematics, that they needed CPD in aspects of teaching and learning in S&HD. Of particular concern to these teachers was the position of the problem solving

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[2] Report available from http://www.cbi.org.uk/pdf/functionalskills0906.pdf

approach itself within statistical investigations. There are, however, many teachers who have their own ideas of interesting contexts that invoke problems that could be addressed using the problem solving approach. We believe that a web-based tool that could be used by teachers to develop their understanding of S&HD through the implementation of the problem solving approach for their own problems would have an enormous benefit. It would be of particular importance, and potentially attractive to teachers, if a by-product of the professional development activity were a PowerPoint presentation and student worksheets for their lessons.

Recommendation 9 - Creating a Portfolio of Resources

We recommend that the QCA should give priority to the development of online CPD resources that will enable school teachers to take ownership of their CPD needs by facilitating the transformation of their own case studies and examples into further resources in the style of those in Recommendation 7.

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3 Assessing the problem solving approach

3.1 Intention

As previously discussed, the results from the national survey of heads of mathematics, science and geography departments made it clear that there was a need for the new resources to be based within the problem solving approach. Of necessity, therefore, the approach that was adopted to assess the effectiveness of the materials required the design of an assessment that would test the pupils' understand of the problem solving approach itself. The intention hitherto, as exemplified by the approach to assessment adopted by the examining bodies, has been that the handling data coursework would assess the relevant part of the national curriculum (which is called the Handling Data Cycle).

In October 2006 the curriculum development organisation Mathematics in Education and Industry (MEI) produced an evaluation of the role of coursework in Mathematics[3]. This report suggests that the intended outcome of coursework assessing students' appreciation of the problem solving approach was not successfully achieved. Evidence from our national survey suggests that many mathematics teachers are unsure of the problem solving approach and by implication were unable to facilitate this aspect of the coursework successfully.

Our task therefore was to find an approach to assessing the students' skills that did not involve the use of coursework. Our approach to the assessment of the effectiveness of the resources started by considering the following two approaches:
- (a) an assessment based on work the students had undertaken previously as part of their classroom activities;
- (b) an online assessment based on previously unseen material.

The Investigative Skills Assignments (ISAs) contained within the new science curriculum[4] provide examples of the approach of (a). In the ISAs it is expected that students have encountered several investigations and they take data from one of these into the examination. Questions are about students' own experiences as well as an unseen case study. The assessment that evolved through this project, while not being of model (a), is heavily influenced by the structure and style of these ISAs.

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[3] This report can be seen by accessing *"Coursework in Mathematics"* available from
http://www.mei.org.uk/News/cwpaper.shtml
[4] See p62 http://www.aqa.org.uk/qual/pdf/AQA-4462-W-SP-07.PDF#int for further information

An assessment based on model (b) allows more flexibility in that it is not constrained by the actual class work undertaken by the pupils and in addition it could allow the possibility for further development as a formative assessment tool.

The developed assessment, although not referring specifically to the pupils' own previously completed investigation, would be based in style and structure on the ISA. The introduction of e-assessment allows the candidate to be treated as an advisor and encourages them to make decisions throughout the test. It is our belief that this not only demonstrates the students understanding in these areas but also presents S&HD in a manner similar to the way it is used in practice by professionals.

In developing the assessment we decided that the questions asked should be composed after a mapping of the curriculum content that refers to the problem solving approach onto the revised Bloom's Taxonomy (Anderson et al 2001) had taken place. This is discussed in section 3.2. One of our greatest concerns in developing an assessment for this context was accessibility to students with low literacy levels. S&HD by its nature is a subject that has high literary demand. In order to minimise this, it was our aim to select a context for the assessment that, whilst having the potential to manipulate data in a variety of ways and at differing levels, would also be easily understood and accessed by students. The choice of the mobile phone context: *Getting the best deal* was therefore selected as we believe that students will be able to immediately appreciate the factors involved and will be able to contextualise the work in their own minds. In addition to selecting an easily accessible context, it is proposed that the assessment should be supported with audio files allowing the reading aloud of text within the test.

3.2 Using Bloom's Taxonomy

Bloom and Krathwohl (1956) published a taxonomy of Educational objectives in which they presented a taxonomy of different forms of learning. The six categories of this 'cognitive dimension', in what is referred to as Bloom's *original* taxonomy, are: application; knowledge; comprehension; analysis; synthesis and evaluation. Bloom's original taxonomy was updated by Anderson and Krathwohl (2001) in two important respects. The first of these was to rename the six categories of the cognitive dimension to reflect their belief that, as thinking is an activity, the different forms of thinking should be described by verbs rather than nouns. The six categories of Anderson's revised taxonomy are: remembering; understanding; applying; analysing; evaluating and creating.

Table 1 of Appendix 6 presents a mapping of the descriptors of the handling data cycle from the national curriculum onto the categories of the revised taxonomy and this allows an analysis of how the levels of the revised taxonomy are implicit in the different stages of the problem solving approach. This table was constructed using the statements on the problem solving approach (the handling data cycle) from the National Curriculum. An examination of Table 1 in Appendix 6 shows that each stage of the problem solving approach requires/involves at least four levels in the taxonomy. Because collecting, presenting and interpreting numerical data are taught as part of the framework 5 strands (DfES 1999, The National Numeracy Strategy) the intention is for all categories of the cognitive dimension to be involved in the learning of statistics and data handling at this level. In the light of our experience in trialling we believe that our resources enable the problem solving approach to be successfully taught to students at least from year 7. The stages of the problem solving approach we have adopted correspond to the stages of the scientific method/enquiry which has been taught to pupils from year 7 in the science curriculum, see, for example, Goldsworthy et al (2000). The teaching and learning resources that we have developed take full cognisance of this conclusion/finding.

The second change made by Anderson and Krathwohl (2001) was to introduce a second dimension which they referred to as the knowledge dimension. The categories of this knowledge dimension, representing the outcomes of the thinking process, are factual, conceptual, procedural and metacognitive. The classification in Table 1 of Appendix 6 was then used, together with a two way table that combines the cognitive process dimension with the knowledge dimension, to produce a mapping of the learning objectives of the problem solving approach to statistical problem solving to produce Table 2 of Appendix 6. This process then naturally identified our starting point for the development of the assessment and its associated questions.

3.3 Soliciting opinions on assessment

Two approaches were adopted to elicit external views on the assessment process that was needed to determine the effectiveness of the new resources. For the first of these, when James Nicholson was approached to review the group of initial resources, he was also asked to provide his views on how they might be assessed. The second approach was to ask Peter Holmes who has recently published a paper on developing assessment for statistics making use of Bloom's taxonomy, Holmes (2002), to provide his views on how the problem solving approach could itself be assessed. The reports from both of these consultants are contained in Appendix 7.

A careful reading of the advice given by both of these consultants reveals that between them they reach the following conclusions:
- the planning and discussion stages are not suitable for formal assessment;
- if they are to be assessed, the preferred way in which the planning and discussion stages should be assessed is through a "portfolio" or coursework based approach.

From this advice it is clear that what we have produced appears to have broken new ground - we embarked on a task that at least two experienced statistics educators did not think could be easily accomplished.

3.4 The online assessment

During the period leading up to and over summer 2006 the QCA underwent a process of considerable internal reorganisation. This has impacted on the latter stages of the project. Briefly:

1. The last Strand Panel meeting was in June 2006, and although a final meeting was due to take place in October, it was decided that this should be replaced by a meeting between the RSSCSE project team, Nick Doran of the QCA and two of the awarding bodies. At the meeting the awarding bodies were very interested in our work on assessment within the project.
2. In October 2006 the QCA called a meeting with members of the mathematics community to discuss, amongst other things, the future of GCSE mathematics including coursework.

At both of these meetings it was made clear that there was a need for the pilot of the new GCSE/Functional maths assessment to be online. These considerations together with the fact that Professor Adrian Smith in his 2004 report, *Making Mathematics Count*, suggested a move towards on-line assessment regimes persuaded us to provide an online assessment mechanism.

The online assessment uses Flash Player to present the assessment tasks to the students. A screen dump of the online pages of the assessment is reproduced as Appendix 8. The assessment consists of three sections, A, B and C, it is intended that a refined version would take one hour to complete.

Section A is designed to test the candidates' knowledge of the problem solving approach and presents them with an edited version of Figure 2.2.1, shown here as Figure 3.4.1.

Figure 3.4.1
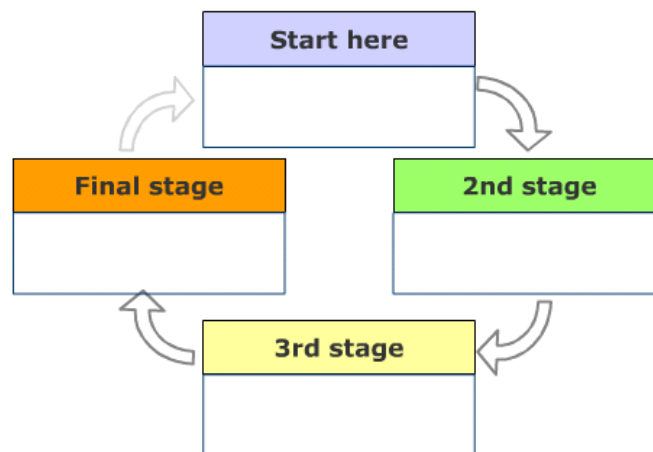
The students are also presented with four descriptions of the activities undertaken during the different stages of the problem solving approach and are asked to drag and drop the descriptions into the correct locations in the figure.

The next question presents them with the cycle (Figure 2.2.1) and asks them to explain in their own words why it is described as a cycle and why this description is important.

Section B starts by describing a case in which a girl, Ayesha, has used the problem solving approach to decide which mobile phone would be the best value for money. Ten statements summarising the process that were written by Ayesha are presented and the candidates are asked to read each of them and then to place each of them (drag and drop) in its correct place in the boxes of the problem solving approach diagram. This is followed by eight further questions that carefully probe the candidates' understanding of what Ayesha did at each of the different stages, and whether or not she was correct in her work.

The final section describes another child, Andy, who also wants to obtain a mobile phone but who, unlike Ayesha, has not completed the problem solving cycle. Instead the candidates are led through eight slides during which information available to Andy is presented and the candidates are invited to help Andy to make some decisions. After some of the decisions the candidates are told what Andy actually did but they cannot return to previous pages to change their responses in line with this. The next stage presents the data that was collected by Andy and asks for suggestions on how the data could be made to look "less messy". The next few slides ask the students to undertake calculations, make comments on the data and to consider suitable graphical presentations and summary measures. The candidates must then type in responses as part of a discussion of what has been found and make a decision as to which phone should be purchased. The final three questions explore the fact that the data used by Andy was not all that was available and leads them to comment on how the problem solving cycle could be revisited if different questions are raised.

3.5 School trialling of assessment material

The assessment was given to a range of students to complete who had experienced the teaching/learning resources developed at the trialling stage of this project. If it had been a long time since they had completed the materials, teachers gave a review of the work they had done, using the original PowerPoint presentation for structure and assistance. The materials are intended to test the students' ability to approach statistics in a holistic manner. The mode of assessment we have developed has great potential for being used formatively in the classroom as well as summatively.

The assessment was well-received by the students and staff who trialled it. Appendix 9 contains notes produced after discussion with experienced classroom practitioners. Appendix 10 contains a response to these comments and should illustrate some of the flexibility and potential that is contained within this form of assessment.

In addition to the factors which led us to choose an online mechanism for the assessment, we feel, and have evidence that teachers support us in this view, that online assessment has several educational advantages over paper-based versions. These include the following:
1. It allows a scenario to be partially revealed.
2. Ultimately, automatic marking could be incorporated into the assessment.
3. Students' responses can be elicited within the structure of someone having already responded.
4. Students are not likely to be overly distracted by technical aspects of a problem.
5. A calculator can be included if needed.
6. *Doing* statistics naturally has a high literacy demand – online assessment can be useful in minimising the effects of poor literacy skills.

3.6 Potential for the assessment

The assessment we have produced is a prototype of a tool which could be used to judge the effectiveness of teaching materials at *different* levels. The structure and approach we have adopted is appropriate for a variety of ages and ability of students. The template could be adapted for a wide range of individual needs. Appendix 9 contains responses to some of the comments that were made by pupils and teachers whilst using the assessment. Some of the technological possibilities contained within the assessment are outlined as a response.

It is our belief that there is potential for further developing the assessment and providing feedback in the following ways:
1. The assessment in its current form allows teachers to give formative feedback by providing responses for the whole group in a spreadsheet. The responses could be mail-merged to produce a completed exam paper for each student; this could also be accessed on screen. Similarly, the teacher could select a particular response to a question and examine the spread of responses allowing students to become accustomed to the idea that there is often no single correct response to some questions in statistics.
2. The potential exists for feedback being provided in the form of a checklist of skills with a guide as to where students have provided evidence of their demonstrating each skill. This could work in partnership with a portfolio of assignments to demonstrate each skill.

It is our belief that the discussion here presents the assessment scheme of this project as a useful mechanism which has much potential for further development and adoption for assessing the effectiveness of teaching problem solving thinking skills.

If this approach is adopted on a wide scale, and there is a subsequent need for automatic marking to be adopted, a natural way to proceed would be to consider a multiple choice structure. Although some authors have expressed concern about the assessment of higher order thinking using this approach, recent work by Bennett, Rock and Wang (1991), Farthing, Jones and McPhee (1998) as well as Haladyna, Downing and Rodriguez (2002) suggest this could be achieved.

The assessment tool can be made predominantly objective. This could allow at least a degree of automatic marking. However, in order to assess higher-order skills, multiple choice questions are, by necessity, more complex in structure. These may only be appropriate for older students, namely KS4 and upwards. However as a starting point we have taken the *MEI Statistics 1 (2613) Coursework Assessment Sheet: Data Exploration* as the basic template (see footnote 3), which we have adapted for use with our online assessment regime. For our purposes we use five domains: the first to allow for the holistic view of the problem solving approach and the remaining four

correspond to the four different stages of the problem solving approach. These latter four domains are repeated for each pass through the cycle. In the assessment presented in Appendix 8 there are two passes corresponding to the problems faced by Ayesha and Andy. The assessment sheet is presented in Appendix 11. We have allocated a single mark for each question asked of the candidates. This allows each of the five domains in the table in Appendix 11 to be given different weightings if an examiner so wishes, these weighting being recorded in the comment column before allocation of marks for the domains in the final column.

3.7 Conclusions for the assessment

Assessment is now a key part of the learning process for students, as well as providing the usual summative judgement of skills and knowledge in a subject. Teaching through problem solving clearly requires a different approach to assessment compared with traditional unseen paper-based examination procedures. We have produced an example of how the use of ICT can produce both a flexible and innovative approach to formative and summative assessment. These considerations lead us to recommendation 10.

Recommendation 10 - Development of Assessment
We recommend that the assessment of the problem solving approach, described as the Data Handling Cycle in the National Curriculum, should be undertaken by using, and further developing, the approach to this assessment developed by this project.

4 Costs and benefits

4.1 Costs of removing some statistics

In assessing the costs and benefits of "... removing some statistics material from the mathematics curriculum" we were first confronted by the need to maintain the content of the compulsory elements of the national curriculum. An investigation into the content of the new national science curriculum and a consideration of the non-compulsory nature of the geography curriculum after key stage 3 led us, in our November 2005 report, to conclude

> *The evidence is that the seeding of statistics through other subjects, such as science and geography, cannot be done effectively by using communality of topics between the statutory requirement in the statistics and data handling part of the mathematics curriculum and the existing curricular in either science or geography. We conclude, therefore, it will not be possible to remove material from the mathematics curriculum and place it instead within the science and/or geography curricula.*

The costs associated with the removal of some statistics from the mathematics curriculum would therefore equate with the costs of removing those aspects of statistics from the compulsory curriculum. We have rehearsed, in Section 2.4 above, the arguments that the statistics content of the national curriculum is inextricably linked to the skills of the UK workforce. For these reasons we believe that these costs can only be measured at the macroeconomic level which could have potentially disastrous implications for the UK economy as a whole.

4.2 Costs and benefits of implementing recommendations

We now consider the costs and benefits arising from the recommendations made in this report. Recommendations 4 and 7 stem from our experience that the resources that have been produced by this project have been well received and engage pupils in activities through which they can learn and develop essential statistical skills. These skills are developed in such a way that

students can benefit from greater integration of subjects across the curriculum. The primary thrust of these two recommendations is that a wide range of resources need to be developed in the immediate future and there is a pressing need for them to be made widely available and affordable for all schools in the country. Waiting should not be an option.

The benefits that such action will have for the future of the UK economy cannot be underestimated. The evidence suggests that there will also be substantial educational benefits from such an approach. These should be set against the relatively low costs of commissioning the development of more and similar resources.

The harsh reality is that without these statistical skills underpinning the research and problem solving activities in academia, not for profit companies and industry, the HM Treasury Science & Innovation Investment Framework 2004 -2014[5] will fail to deliver its objectives.

Similar cost and benefit considerations apply to Recommendations 3 and 8 in relation to the CPD that is needed for mathematics (and other) teachers who are required to teach statistics. The need, at a national level, for teachers to have the necessary skills to teach statistics is self-evident. Again, the relatively modest costs of a comprehensive programme to implement these recommendations should be set against the benefits to the nation as a whole. However we draw attention to Recommendation 9, which urges the development of a 'wizard' to enable combination of both CPD and development of resources at a local level. Implementation of this recommendation, when taken together with an intelligent adoption of Recommendation 11, would help to reduce the costs associated with the development of resources at the same time as providing an additional benefit from the point of view of CPD.

Insofar as we believe that our approach to the assessment can successfully examine understanding of and ability to use the problem solving approach, we believe that it goes some considerable way towards addressing concerns about assessing essential skills that have been expressed by leaders of industry and commerce. Implementation of recommendation 10 should therefore bring considerable economic benefits for a modest investment.

5 Dissemination

We have had two opportunities to disseminate the emerging findings of the project. First, the NCETM was officially launched at the end of June and memory sticks containing RSSCSE resources were prepared and given to all attendees on the day of the launch. One of these resources comprised a description of the first four problems devised for the project and can now be found on the NCETM website at www.ncetm.org.uk/.

Second, the RSS *Statistics across the Curriculum Roundtable* held a meeting in July 2006, at which early findings of the project were presented, including details of the problems and plans for assessment.

The International Association for Statistical Education (IASE) is holding a conference on Assessment in Statistics in Portugal in August, and the RSSCSE has been invited to present a paper. We will be reporting the results of the QCA project.

Finally, in the early stages of the project, it was agreed that the QCA should sponsor a conference to disseminate the findings of the project to the teaching community in the UK. The RSSCSE would welcome the opportunity to engage with as many teachers as possible.

We are anxious that, even though there appears to be no further funding to continue with the creation of more problem solving resources, the project should not end. We suggest that one way

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[5] www.hm-treasury.gov.uk/spending_review/spend_sr04/associated_documents/spending_sr04_science.cfm

to do this would be through a conference and/or workshop. Our final recommendation concerns this.

Recommendation 11 - Dissemination

We recommend that a national conference/workshop be organised by the QCA where teachers can learn about the resources and get involved with the creation of further ones in line with recommendations 9 and 10. This could be done under the auspices of the National Centre for Excellence in the Teaching of Mathematics.

We also seek permission from the QCA to make the teaching and learning resources we have developed freely available freely available through the NCETM website.

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