The Fibonacci Project

DISSEMINATING INQUIRY-BASED SCIENCE AND MATHEMATICS EDUCATION IN EUROPE

COMPANION RESOURCES FOR IMPLEMENTING INQUIRY IN SCIENCE AND MATHEMATICS AT SCHOOL

INTEGRATING SCIENCE INQUIRY ACROSS THE CURRICULUM

WITH THE SUPPORT OF
EUROPEAN COMMISSION

Resources for Implementing Inquiry in Science and Mathematics at School

The Fibonacci Project (2010-2013) aimed at a large dissemination of inquiry-based science education and inquiry-based mathematics education throughout the European Union. The project partners created and trialled a common approach to inquiry-based teaching and learning in science and mathematics and a dissemination process involving 12 Reference Centres and 24 Twin Centres throughout Europe which took account of local contexts.

This booklet is part of the *Resources for Implementing Inquiry in Science and in Mathematics at School*. These Resources include two sets of complementary booklets developed during the Fibonacci Project:

1) Background Resources

The *Background Resources* were written by the members of the Fibonacci Scientific Committee. They define the general principles of inquiry-based science education and inquiry-based mathematics education and of their implementation. They include the following booklets:

- 1.1 Learning through Inquiry
- 1.2 Inquiry in Science Education
- 1.3 Inquiry in Mathematics Education

2) Companion Resources

The *Companion Resources* provide practical information, instructional ideas and activities, and assessment tools for the effective implementation of an inquiry-based approach in science and mathematics at school. They are based on the three-year experiences of five groups of Fibonacci partners who focused on different aspects of implementation. The *Companion Resources* summarise the lessons learned in the process and, where relevant, provide a number of recommendations for the different actors concerned with science and mathematics education (teachers, teacher educators, school directives, deciders, policy makers...). They include the following booklets:

- 2.1 Tools for Enhancing Inquiry in Science Education
- 2.2 Implementing Inquiry in Mathematics Education
- 2.3 Setting up, Developing and Expanding a Centre for Science and/or Mathematics Education
- 2.4 Integrating Science Inquiry across the Curriculum
- 2.5 Implementing Inquiry beyond the School

Reference may be made within this booklet to the other *Resource* booklets. All the booklets are available, free of charge, on the Fibonacci website, within the *Resources* section.

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WWW.FIBONACCI-PROJECT.EU

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Integrating Science Inquiry Across the Curriculum

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Focus of this booklet

This booklet is aimed at teacher educators and teachers. It summarises work undertaken, within the Fibonacci Project, by organisations from England, Estonia, France, Ireland, Luxembourg, the Netherlands and Romania. The focus is on investigative science education. It reflects the working groups' specific expertise and school-based trials. As the majority of members have focused on work with primary teachers, most examples cited come from teachers in the 6-12 age range.

The members of the working group consider that there are real gains to be had by overtly linking investigative science with other subjects being taught in the school. The choice of second (or third) subject depended on the needs of the teachers and pupils in each country. For example, educators in the Netherlands were already developing ICT hardware for improving data logging in science, so they explored ways to use ICT to enhance investigative science.

The working group considers that it was more important to cater for the needs of pupils and teachers than to trial links between every subject and science. Consequently, we report on some aspects in greater depth than others. While we suggest generalisations based on our findings, this is very much 'work in progress'.

What is 'science inquiry across the curriculum'?

The Fibonacci Background Booklet 'Learning Through Inquiry'[1] provides a general definition of what we mean by 'inquiry' in the Fibonacci project and gives some indications of how science education might be enhanced by links with other subjects such as language, mathematics, history, art, geography, sport and health education. While educational literature suggests different strategies for linking more than one discipline (see Appendix), our particular approach is to make links between different school curriculum areas to support learning in each subject.

> It is essential not to lose sight of the aim to focus both on <u>developing inquiry methods</u> and improving pupils' <u>learning</u>. It is important to have clear learning objectives in <u>each</u> separate subject in any activities developed.

Approaches in primary and secondary education

The way of 'integrating science inquiry across the curriculum' varies, often depending on whether there is a primary or secondary education focus. Primary school educationalists tend to think of making links between science and other subjects such as mathematics, language and history. This reflects the fact that primary schools usually employ generalist teachers who teach all subjects. In contrast, secondary school educationalists often focus on making links between physics, chemistry and biology. This reflects the current tendency that these subjects are taught and examined separately. It is also unusual for secondary science teachers to work with colleagues teaching other disciplines.

Note: we use 'science' to mean natural science which deals with the natural world, its objects and phenomena as described in 'Learning through Inquiry'

[1] Available on www.fibonacci-project.eu, within the *Resources* section.

Links with a single subject or topic work

One approach is to take one subject (science or physics) as the focus, with other subjects being related to a lesser or greater amount. On the other hand a topic such as 'Water' or 'Environmental Issues' can be developed with information from a variety of subjects applied as appropriate. It appears that the topic approach is more common in secondary schools and kindergarten/pre-school classrooms, whereas the former is more common in primary schools.

The majority of examples in this booklet are focused on taking science as the central subject with one or more subjects linked to it in a progressive way. This avoids the risks of a topic approach, where teachers with limited expertise in science only focus on factual elements that can be learnt by rote or lose sight of the objectives of developing inquiry methods alongside improving pupils' learning concepts in science and other subjects. This is less likely to occur with secondary teachers who have in-depth knowledge in science. Consequently some examples of topic work from secondary schools are included in this booklet.

Rationale for developing hands-on integration of inquiry across curricula

Sections of the Fibonacci Background Booklet 'Learning Through Inquiry' provide an introduction and rationale for cross-disciplinary approaches in inquiry. One of the most important is that 'mathematics and natural science lessons can be embedded in a whole cognitive development of the child'. There are many advantages to this approach:

- When successful, pupils find learning easier because it is less disjointed and more relevant. Consequently the pupils are more motivated. As only one context is used, language demands are related as the same words recur. This is particularly important where there are many different languages spoken in the classroom.

- Pupils are enabled to use similar skills in different subjects with the same context or problem. They are helped to see that events do not happen in isolation, thus showing the relevance of science ideas and skills in a wider context. Knowledge in the real world is not applied in bits and pieces but in an integrative fashion. This is increasingly important as modern technology is changing access to information, defying lock-step, sequential, predetermined steps in the learning process (Kysilka, 1998). After all, when pupils find information on the internet it is not usually presented in separate 'school' subjects.

- Pupils are more likely to develop creativity, critical thinking and problem solving abilities as they become more familiar with recognising the complex demands of problems requiring knowledge and skills from more than one subject.

There are of course disadvantages. It is important to be aware of these so that advantages can be optimised and disadvantages minimised. If all subjects are linked to a theme, such as 'Water' or 'Festivals', some subjects may not always fit logically within the theme, with the possible result that the skills and concepts of these subjects are inadequately addressed. Ensuring progression and continuity of skills and knowledge in all subjects is a major challenge. It is for this reason the working group felt that making good links between science and only one or two subjects initially is important. It takes considerable time for teachers to make effective links between many subjects. Research as part of the Pollen Project[2] indicates that there are several stages in moving toward a whole-school cross-curricular approach, which take several years (Jarvis, 2009). Therefore the working group took a developmental approach with the view to enabling teachers to link science with other subjects in a way that teachers are able to plan and assess genuine progressive skills and concept learning in all subjects.

[2] http://www.pollen-europa.net

Progressive stages to achieve good integration

Over the course of the Fibonacci project, the working group developed a progression aimed at full integration of two or more subjects. While we recognise that various models might explain progression towards this aim, we suggest one that we find helpful.

Initially teachers and pupils need to understand an inquiry approach and develop confidence and some competence in the concepts and skills of the subjects they are linking. It was clear from research and practice that this process would take several years (Jarvis et al., 2011). Previous experience in the Pollen Project and trials with the Fibonacci teachers indicate that it is better to link science with one other subject first – reflect, evaluate, learn then link with another. Slow and steady progress is more effective in the end.

Stages of the developmental process:-

1. Pre-requisites

i) Motivation and understanding of inquiry and nature of science investigations

ii) Some knowledge of science concepts and science subject knowledge

2. Development of concepts and skills of mathematics, ICT and/or literacy

Mathematics, language and ICT are natural partners with science and improve communication of science ideas. They are therefore central to a cross-disciplinary approach.

i) Mathematical skills such as measuring and understanding scale

ii) Use of ICT as a tool to support science / mathematics such as data logging

iii) Literacy skills such as oral discussion, reading and writing

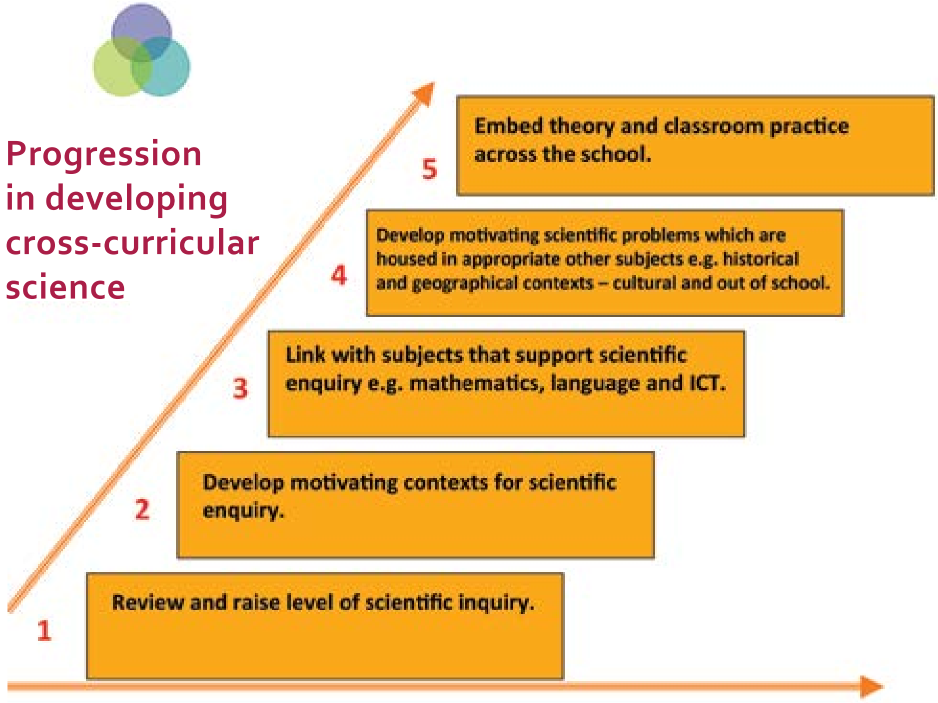
3. Providing contexts for science investigations using other subjects

It is important to show that science is relevant in society. Links with other subjects in the curriculum are therefore important.

i) Local community activities such as school sport and out-of-school activities

ii) Subjects such as history and geography which give real social context for science that occurred in the past or is relevant in different locations today

4. Fully integrated science investigations with learning objectives achieved in all linked subjects



The model presented by Rosemary Feasey at the Fibonacci Seminar 'Integrating Inquiry Across Curricula' held in September 2011 at the University of Leicester was particularly useful in summarising the working groups' ideas.

Pre-requisites

Motivation through practical inquiry-based investigations

Research based on the Pollen Project and other long-term in-service education showed teachers' ability and speed to adopt new pedagogical ideas, such as hands-on investigative science, was strongly affected by their attitudes to science as well as their self-confidence in their science knowledge and scientific pedagogical skills (Jarvis et al., 2011). Initial self-confidence in both science knowledge and the pedagogy of teaching science are major factors. Without both, improvements in the classroom may not occur or there may even be a negative effect. It is not appropriate to start making links with science until teachers understand the nature of science investigation.

Once the teachers have enough confidence and ability to successfully apply their new knowledge and skills in the classroom, pupils' response is very important. If the teachers are able to present the lesson satisfactorily, the pupils usually react with increased interest and behave well. This motivates teachers to continue the new approach. Consequently, it is important that development of cross-disciplinary activities support and enhance pupils' motivation. Fortunately we found that an integrated inquiry curriculum was motivating as it made the inquiry more realistic. However, it needed to be planned over time. It was more effective if teachers provided gradual learning over several weeks so that pupils felt that they were building deep and lasting knowledge and skill. Support of the process by senior leaders was essential. Pupils also needed the freedom to make errors and try to correct them for themselves, supported by adults if necessary, as well as the chance to share results and ideas with peers.

Developing an understanding of the nature of science investigations

Much research has been conducted on the importance and benefits of teachers and pupils having sound conceptions of the nature of science (NoS) (Abd-El-Khalick and Lederman, 2000; Craven et al., 2002; Akerson et al., 2010; Murphy et al., 2011). Some research suggests that the incorporation of NoS as part of science curricula makes pupils more aware of the developmental nature of science and humanises science therefore making science more interesting and relevant to them (McComas, Clough and Almazora, 1998). Others contend that students who leave school with contemporary understandings of NoS have a better understanding of science concepts and scientific inquiry, a greater interest in science and have a better appreciation of science's role in contemporary society (Matthews, 1994: Lederman and Abd-El-Khalick,1998; Murphy et al., 2011). It has also been reported that when teachers teach about NoS they more frequently employ inquiry-based approaches to teaching science and there is increased motivation and interest in science amongst their pupils (Murphy et al., 2011).

Primary teachers who have little experience of teaching science, and inquiry in particular, need to develop conceptual and pedagogical understanding of the nature of science. The approach taken with Fibonacci teachers in Ireland has been to develop a series of practical activities to develop the skills that underpin all science investigations. By becoming more aware of the process of good science investigations, pupils' investigative work becomes more robust. The pupils are also using oral language in cooperative situations which supports their language development.

The Dublin team has adapted and developed several activities that overtly teach pupils about how scientists work[3]. These activities have enabled teachers and teacher educators to become more aware that:

- There is an important difference between observations and inferences;
- Inferences must be based on evidence;
- The objectives of investigations are to produce predictions or hypotheses that explain phenomena scientifically;
- This process of deduction requires logic and creativity;
- Different groups of pupils' / scientists' deductions or hypotheses can vary even given the same information;
- While investigations should control variables, different groups of pupils / scientists can interpret the objective (as in defining 'best bubble') and use different methods;
- The methods used must be acceptable to the scientific community and pupils/scientists must ensure that their chosen methodologies are reliable and repeatable;
- Sharing with other groups, scientists or scientific institutions can help to achieve a better hypothesis; and
- There are virtually always gaps in scientific observations and results, consequently pupils/scientists must be prepared to accept uncertainty and be prepared to rethink their ideas.

Magnified images

'Magnified images' gives pupils pictures of a variety of highly magnified parts of objects. The pupils are asked to talk about their observations and then infer from these pictures what the objects might be. The pupils learn to distinguish between observation and inference. They discover that different people make different inferences from the same information. They are not told what the objects are at the end of the session so that they start to appreciate that scientists have to accept uncertainty. 'Tricky Tracks' is a similar activity focused on observations and deductions. http://www.fibonacci-project.ie/activities-tricky-tracks.html

[3] Teacher trainers who wish to have the DVD should contact cliona.murphy@spd.dcu.ie and it will be posted to them. It can only be used for teacher training purposes.

The mystery box

'The mystery box' makes different noises when shaken. The pupils are asked to conjecture what might be making the sounds and how. They are required to support their theories by deduction. When they are given the additional information that the contents come from a typical kitchen, they recognise that this assists by narrowing down their options. This replicates the process of refining and improving hypothesising as additional data is collected. Black-box activities present children with challenges similar to those encountered by scientists. Scientists are often presented with problems where they don't have all the information – so it is like a 'black box' where they can't see inside. They still have to use what they can observe to come up with theories about what is happening.

The 'hole' picture

'The hole picture'[4] sets out to help pupils to make deductions from very limited data, where, like some scientists, it may never be possible to have all the information about the 'whole' picture (e.g. astrophysicists). Different groups are given the same photograph which is covered but has small holes that show the underlying picture. The pupils have to suggest what the picture might be. Then they are asked to improve or rethink their deductions after sharing information with other groups who have the same picture with holes in different places.

Pupils' suggestions for what the 'hole picture' might show.

The cube

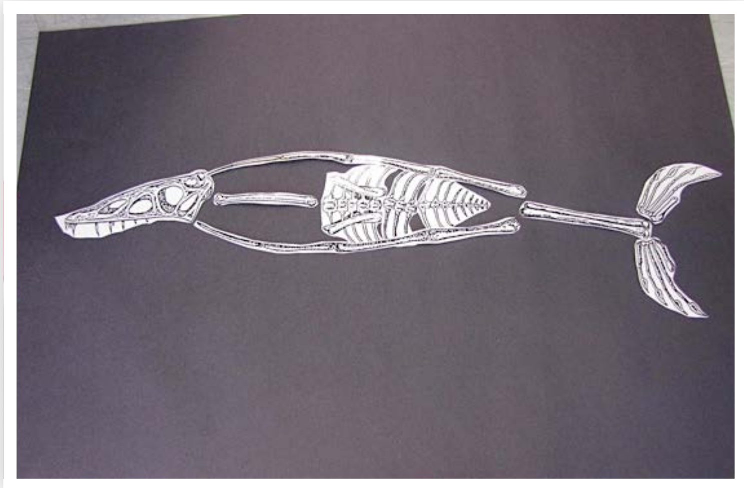
'The cube' has simple words on the faces of a cube. All the words (e.g. fat, bat, hat) are linked in a logical way. The pupils are asked to deduce the word on the one face that is hidden. In the same way scientists use patterns in their observations to make deductions and hypotheses. Towards the end of the activity, the groups of pupils discover that their deductions, while logical, are not the same as other groups. In the same way scientists do their best with the data they have but must recognise that there are no fixed answers.

[4] The hole picture and cube activities have been adapted from Lederman and Abd-El-Khalick, 1998.

The bone expedition

'The bone expedition' takes the story of palaeontologists who uncover fossil bones over several days. At first each group finds two 'bones' (diagram of bone or group of bones) and is asked to think about what creature they might have unearthed. On subsequent 'days' they discover other bones and improve their deductions. As different groups have been removing the bones from their envelopes in a different order, each group has different bones and deductions. The pupils then visit other groups ("universities") to share knowledge. Finally they are given diagrams of a range of fossils to see whether there are similarities between their bones and existing deductions by researchers. http://www.fibonacci-project.ie/activities-the-great-bone-expedition.html

Pupils discussing their bones



One suggested complete fossil

By teaching these approaches and attitudes separately from specific investigations aimed at developing science knowledge and concepts, Irish teachers have become more confident in science and investigative methods. Their pupils have become more enthusiastic about science. They have a better understanding of science concepts and skills as well as having had more frequent, focused use of inquiry-based science. The pupils have been reflective which has improved learning and quality of argumentation. The group oral discussion has improved their use of language and cooperative skills. They have been enabled to combine hands-on activities with reviewing science literature and existing resources.

Identifying steps of an investigation

An alternative approach to assist teachers in understanding the way scientists work and how a real scientific investigation goes on was adopted during professional development sessions run in Bucharest by the Centre for Science Education and Training team. After a short group discussion on the objectives of science teaching in school, each attendee received a sheet of paper where several squares were marked with possible steps belonging to a science investigation process. Some of the labels gave real steps encountered during a scientific investigation but some were false, but with convincing wording. Teachers attending the course were asked to set out the labels in the order they thought a scientific investigation takes place. At the beginning they worked individually. After some time the discussions were debated in small groups. Individual / group ideas were analysed with the whole class. The exercise helped them to understand the importance of critical thinking and of the appropriate use of scientific terminology. Inaccurate language can induce confusion and mislead the investigator.

Developing links with mathematics

There are potential advantages in integrating mathematics and science which can enhance the learning of both subjects, and in particular support the learning and teaching of statistical thinking. But to achieve these goals, integration must go beyond a superficial approach, such as identifying where mathematical ideas might be taught 'in preparation' for where they are needed in science, or 'spotting' mathematical shapes and patterns in nature.

There is a widely recognised concern within mathematics education about the separation between 'school mathematics' and the ways in which mathematics is used in everyday life, which is not adequately addressed by traditional attempts to contextualise the school mathematics curriculum (e.g. Boaler, 1993, Cooper and Dunne, 2000, Ainley, 2011). Ainley and Pratt have argued that this separation inhibits the development of an understanding of the *utility* of mathematical ideas, that is, why and how the ideas are useful (Ainley et al., 2006), and that opportunities to develop an understanding of *utility* can be created in pedagogic tasks that have *purpose* for learners. Scientific inquiry offers a rich source of such purposeful tasks in which the *utility* of mathematical and statistical ideas can be embedded.

'Big' mathematical ideas play an important role in the explanatory power of models in science which is not generally exploited in the primary school curriculum. For example, in order to understand why a small child might get cold more quickly than an adult and thus need more layers of clothing; why large sugar crystals dissolve more slowly than regular sugar; why penguins huddle together for warmth; or why elephants have such big ears, it is necessary to have an understanding of volume and surface area and how the proportions vary in different shapes.

Finally, scientific inquiry provides a purposeful context for the collection and use of data of various kinds. This contrasts with the approaches to data handling frequently found within primary school mathematics (in England), which tend to fall into two categories. Either ready-made sets of (clean) data are provided for children, with little consideration given to how or why the data might have been collected, or children themselves collect data about a familiar context (such as the colours of cars in the car park, or how they travelled to school), and 'handle the data' to produce graphs, but without any real purpose which might stimulate more than a superficial reading of the graphs produced (Pratt, 1995). In contrast, during the course of a scientific experiment, decisions have to be made about which data to collect, how best to collect it, the most appropriate way to display it, and how to interpret the resulting graphs and tables. In addition, the data collected will be messy: issues about appropriate accuracy, variability, and the utility of average are both visible and of real importance.

As part of the preparation before meeting the teachers involved in the Fibonacci Project at the University of Leicester, two science educators (Tina Jarvis and Frankie McKeon) prepared an activity sequence to develop a particular concept in science through an inquiry approach. The mathematics educator (Janet Ainley) then identified and developed the opportunities for mathematical and statistical ideas to be used purposefully (such as the use of place value in the scales on measuring instruments), and for mathematical thinking to offer explanatory power (such as proportional thinking about volume and surface area). After exploring two or three scientific topics in this way, a relatively small number of 'big' mathematical/statistical ideas emerged as underpinning very different areas of inquiry in science. These were:

- Instruments and measuring
- Averages, variation, appropriate accuracy and sample size
- Active Graphing
- Looking for patterns
- Classifying and exploring the significance of shape
- Models in science and mathematics
- Area, Perimeter, Volume, Ratio and Proportion

Instruments and measuring

A wide variety of instruments is used in science. These are worthy of close scrutiny and exploration to support children's understanding of the measurements made and results obtained in their investigations as well as their comprehension of the underlying concepts. Most instruments have scales and need mathematical skills to be read or be designed and made.

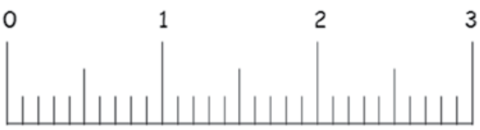
Using and creating scales: An example sequence

1. Examining instruments measuring length

Pupils can be given a variety of different types of length measures such as rulers, tape measures, trundle wheels, callipers etc. that are used in mathematics and science. They can be asked about the variation in scales e.g. What units does it use? What is the beginning and end of the scale? What are the scale intervals?

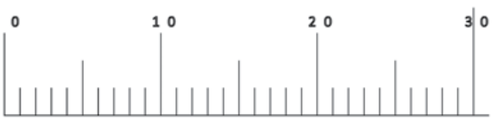
Apart from choice of imperial or metric units (inches or centimetres) there are likely to be two main ways of marking a scale:

Each division numbered – a simple number line

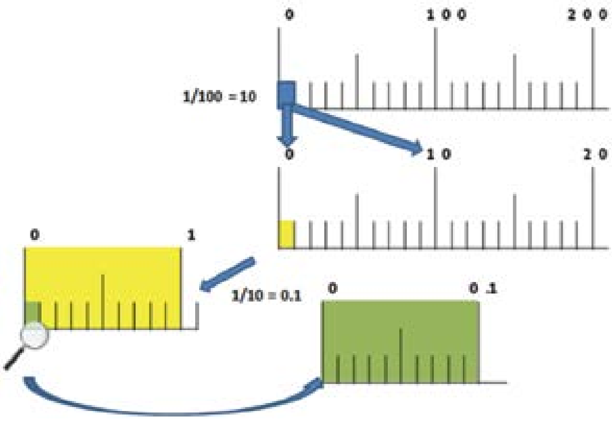


Main divisions numbered with unmarked sub-divisions – a structured number line

Structured number lines are very commonly used in measuring instruments, but may be marked in very different ways. The usual structure mirrors the base ten number system.



The structured number line can provide a model of place value.



Once the pupils have looked at the scales, further questions can be asked that focus more on its scientific purpose e.g. How do you use it? When is the instrument used? What does it measure?

2. Choosing and using instruments measuring length

Children might consider the best device for making particular measurements such as the height of their chair or width of the room. They will need support to consider the appropriateness of the instrument for the task and the accuracy required when making a particular measurement i.e. to the nearest m, cm or mm.

Use of measuring instruments to investigate distance toys cars travelled using an elastic 'catapult'

A class of 7-9 year olds were investigating the effect of using elastic, like a catapult, to propel a car forward along the ground. They wondered if the amount of pull would affect the distance the car travelled. The children chose equipment for measuring the distance the elastic band was pulled back and the distance travelled by the car. Some chose a metre trundle wheel but experienced difficulties measuring the distance the elastic pulled back which was a small distance. Others were confused by a tape measure which was marked in mm on one side and cm on the other. They were inconsistent in their use and unclear about the difference. Another group was perplexed when the car was propelled further than the length of their measure. Those children who initially selected inappropriate equipment soon discovered this by undertaking the investigation.

3. Examining scientific instruments

It is important to ask children to look at instruments they will use in science investigations. This will give them a better appreciation of their results as well as help them choose the correct instrument. For example they might spend some time studying a thermometer before using it in an investigation. Questions will help their observations: Why are thermometers needed? Is it a linear scale? What is the range? Is it marked in 1s, 5s or 10s? If there are different scales such as Fahrenheit / Celsius what are the differences between the two scales? What are the advantages and disadvantages of the two scales?

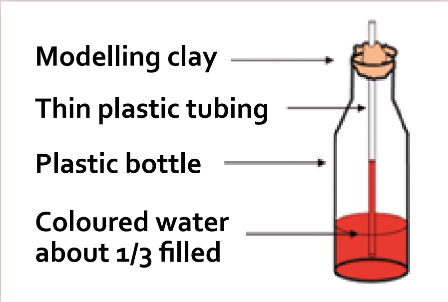
4. Thinking about the beginning and end of a scale

To create a scale you need some measurements you can be sure of. In the case of thermometers this can lead to study of scientists in the past. As Fahrenheit was not confident in the reliability of the freezing and boiling points of water, he fixed his zero point by using the freezing point of a mixture of ice and salt as this gave him the 'most intense cold obtainable artificially'. His other fixed point was the temperature of the human body, which he put at 96°. Given these two fixed points he worked out the freezing and boiling points of water as 32° and 212°. One advantage of this system is that, for most ordinary purposes, negative degrees are rarely needed. Celsius later found that boiling water was affected by pressure, but found a rule to take account of pressure differences. His original scale had 100 for the freezing point of water and 0 for the boiling point. A year after his death, the scale was reversed by Linnaeus to make measurements easier.

5. Pupils make a simple instrument to develop understanding of how the instrument works.

A thermometer can be made by using commonly available materials (see below). Alternatively this can be done as an on-line virtual approach. In Romania a series of educational movies has been developed. These investigate the way to build a thermometer (selection of the reservoir – volume, shape; the tube – length, diameter; the liquid to fill it – density, colour) and to grade and calibrate it. In such an approach, children investigate and learn to optimise an instrument and understand the way it works.

Making a thermometer



Place the bottle in a beaker of hot water.
What happens to the level of the coloured water?
Put it in a beaker of cold water. What happens?

The thermometer is more successful if the tubing is thin plastic rather than glass, and the bottle is only partially filled with water. More water takes longer for the movement of level to be seen. The larger amount of water takes time to reach a new uniform temperature. Manufactured thermometers contain small amounts of liquid so it can be uniformly heated quickly.

6. Looking at different types of the instrument.

In this activity pupils might look at different thermometers (oven, freezer and medical thermometers) to see differences in range of scale and design.

Examples of investigating science instruments and linked mathematical investigations

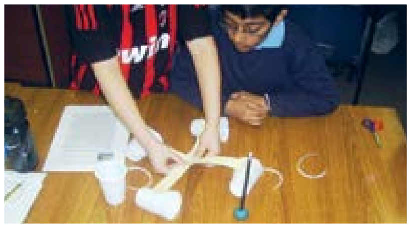
During the Fibonacci project, teachers and pupils in Leicester have examined, analysed and used a variety of mathematical and science instruments in investigations, including: weighing machines; equipment measuring time, length and capacity; anemometers, rain gauges, force meters, blood pressure monitors and stethoscopes.

Example format for focusing observation of instruments

Device	What units does it measure?	What is the beginning & end of the scale?	Comment on the scale intervals	How do you use it?	When is the instrument used? What does it measure?	Comments & Problems
Forehead thermometer	Centigrade Fahrenheit	35 – 40 degrees 95 – 104 degrees	Whole numbers in one unit intervals Inconsistent scale, including decimals	Put it on the forehead and wait	When a human is ill to check if body temp is too high or low.	The recordings fade once off the forehead. If you use it yourself you need a mirror. This makes it difficult to read.
Clinical thermometer	Centigrade Fahrenheit	35 – 42 degrees 94 – 108 degrees	Individual numbers split into 10ths Twos, split into 10ths	Put under tongue.	When a human is ill to check if body temp is too high or low.	Healthy temp. marked in red Mercury – dangerous if broken. Can't use in primary classroom
Stop watch	Minutes, seconds & 100ths of a second Some show hours	0 to ??(99)	Digital no scale	To time phenomena / situations	Wide number of uses.	
Stethoscope	Heart beats	N/A	N/A	Monitor heart rate and quality of heart beat	Used when someone is ill for diagnosis	
Weighing machine	Kilos Stones	0 – 120kg 0 – 19 stones	10s split into 10 individual units Individual numbers split into 7th s	Usually stand on it	Monitor weight change	Needs to be on a hard surface otherwise results not accurate
Callipers	Centimetres	0 – 60 cms	Individual numbers with 10s in larger print	Measuring length of an item	Variety of things e.g. foot length	There are different callipers. This one doesn't measure fine differences

Anemometers

A mixed age lunchtime club and 10-11 year olds examined manufactured anemometers. Then made their own and tested them outside. Once the pupils had made their measurements, they counted rotations per minute. Each model anemometer was satisfactory for comparing daily wind speeds. However as the arms of the anemometers varied, it was not possible to compare data from different models. To achieve this, the rotations per minute would have to be converted to a standard measurement such as metres per second. The first step would be to know how far the cup travels in one rotation. The pupils could have done this by measuring the circumference or calculating it using π.



Measuring lung capacity

After having tried out the experiment during a Fibonacci workshop, teachers felt confident in doing similar work with their pupils.

One class of 11 year old children used balloons to measure their lung capacity. They recorded the circumference of their balloons as a measure for comparison. They then investigated whether there was any link between height and lung capacity. The pupils went into the playground, lined up in height order and then inflated their balloons. They were able to see that in most cases taller people appeared to have larger balloons. Next they exercised and re-measured their lung capacity. They were particularly interested in results from two boys, one of whose lung capacity had decreased a lot and the other whose balloon size had decreased very little. The first said he did not do very much exercise whereas the second was involved in many sports.

Measuring the circumference of the balloon, or the diameter (as in the photo), gives a measure which is proportional to the volume. Older pupils might investigate these relationships.

Averages, variation, appropriate accuracy and sample size

The University of Leicester team found that teachers and trainee teachers had the view that they only needed to repeat an experiment 3 times and find the mean to get a robust answer. The teachers knew that they should encourage pupils to repeat experiments but had no strategies for deciding on how many times (sample size). They did not think about the factors that influence variation. Once this issue was addressed with the teachers, they included these ideas within their pupils' investigations.

Investigations exploring variability

1. Parachutes – factors influencing variability

There are many possible investigations that can be undertaken with model parachutes. There are two levels to consider:

- Macro level: effects of changing one variable (see possible investigations below).

Time how long it takes for your objects to fall with and without the parachute Do several drops and see if the time is always the same or if it varies somewhat	time / variability
Use the same parachute, compare results using two or more different weights	size
Lengthen or shorten the suspension lines	proportion
Change the number of suspension lines	proportion / shape
Try different shapes for your parachute e.g. round, oval, rectangular, square	shape
Cut holes and/or slits in the parachute fabric	air flow / air resistance
Try different materials for the parachute	air flow / air resistance

- Micro level: variability in results within each value or variable

Micro variations occur because of:

- Limited descent distance that pupils can safely use;
- Ambiguity over the height of the drop (from the top of the canopy or the load);
- Inaccuracies with release time of parachute timer control;
- Short times involved – difficult to minimise inaccuracy;
- Problems with larger parachutes' canopies not opening properly; and/or
- Some buffeting with the larger parachutes.

Alongside these variabilities of experiment design and procedure, there are issues where the timing devices can give unrealistic ideas of the accuracy of the tests because they are recorded to one or two decimal places. Pupils are seduced into thinking their results are accurate.

Consequently pupils need to:

- Make a reasoned prediction using prior experience and existing knowledge;
- Observe the action of phenomena being investigated – e.g. problems with large canopies not opening;
- Critically analyse
  - i) instruments/tools used, and
  - ii) measurements made and data collected e.g. short times make it difficult to distinguish differences; as well as
- Consider variations due to investigator action.

2. Parachutes – thinking about sample size

By looking at the data produced, the investigator can not only consider how robust their results are, they can also be helped to decide on their sample size.

One group of trainee teachers was looking at the effect of the size of square parachutes. The results appear to show an accurate difference, but there is only 0.06 seconds between a parachute with a side of 20 cm compared to one with a 30cm side. They needed to repeat their investigation.

Length of side of parachute	Time for descent
No parachute	0.69sec
10cm	0.78sec
20cm	1.28sec
30cm	1.22sec

A second group looked at the effect of the type of material the parachute was made from. Here the differences between types of material was the focus. In this case the differences are so great between the results, there is less need for the investigation to be repeated.

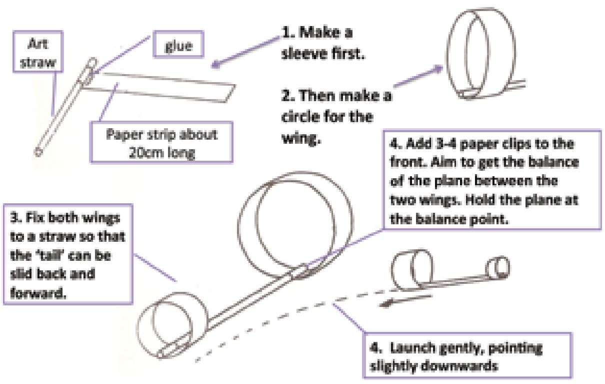
Material	Time for descent
Green hessian	4secs
Orange cotton	9secs
White muslin	5secs

Hargrave's glider – considering sample size

About 100 years ago Lawrence Hargrave (1850-1915) experimented with model flying machines in New South Wales, Australia. Much of his work was done with models. It was cheaper and safer than using full-size machines. He kept careful notes of his experiments. He tried different shapes. He found a curved wing has more lift than a flat one. Therefore he investigated cylinder gliders. This investigation uses his ideas as a basis.

Teachers and pupils were asked to investigate 'Does the difference between the 'wings' make any difference?' Initially there did not appear to be any pattern in the results. The pattern only appears as more trials are done. The flight length for each wing distance overlaps (see table below). The teachers discussed the reasons for the variability – such as difficulties of keeping the launching process consistent and accurately identifying the point of landing.

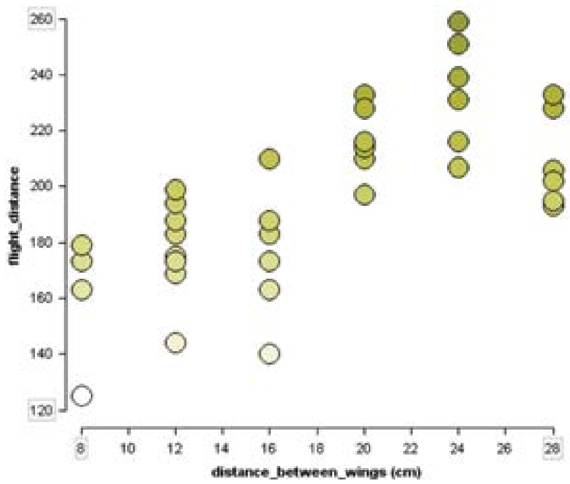
Making Hargrave's Cylinder Glider



Flight distances (mm) when the distance between the wings is varied

Distance between wings	8 cm blue	12 cm white	16 cm red	20 cm yellow	24 cm dr blue	28cm green
	125	144	140	197	207	193
	163	169	163	210	216	195
	163	173	173	214	231	202
	173	175	183	216	239	206
	173	183	188	228	239	228
	179	188	210	233	251	233
		194			259	
		199				
Average	163	178	176	216	235	210

In this investigation, it was important to repeat trials until a pattern emerged. This pattern (hypothesis) could then be tested by trying additional or intermediate variables. The investigators also need to consider whether the extreme results / anomalies (outliers) should be omitted as likely to have been the result of experimental / measurement error. If the data is graphed, the developing pattern can be more easily seen. It appears that there is an optimum distance between wings; somewhere between 20 and 26 cm. Further trials might focus on this area.[5]

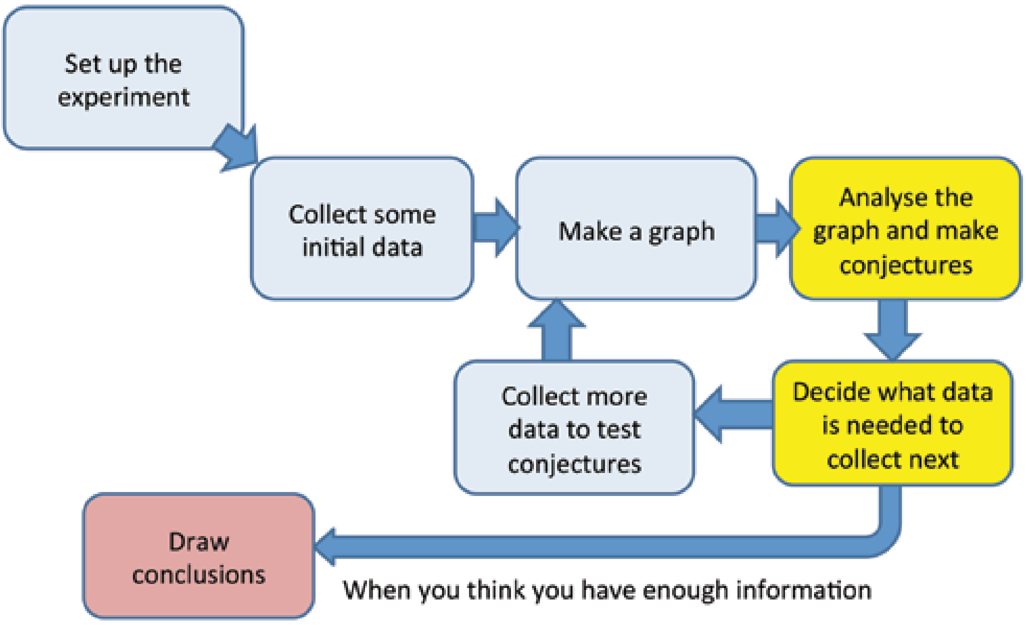


[5]The teachers in Leicester used TinkerPlots software to create graphs of their investigations. Tinkerplots is produced by Key Curriculum (http://www.keycurriculum.com/). We are grateful to Key Curriculum for giving us access to Tinkerplots 2 as Beta version testers.

Active Graphing

During an investigation, if pupils record and illustrate their results as they go along, they can use the results to decide on their sample size as well as which variables to explore further. This process also promotes greater understanding of graphing because there is a constant link between action and the graph. The diagram below shows the process constantly reviewing the graph to make changes in the experimental procedure (Ainley et al., 2000).

Using Active Graphing for an inquiry

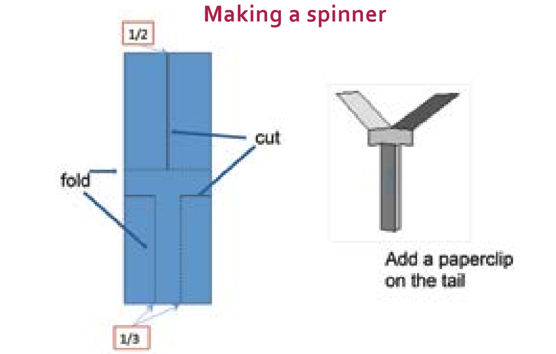


An example: Investigating spinners

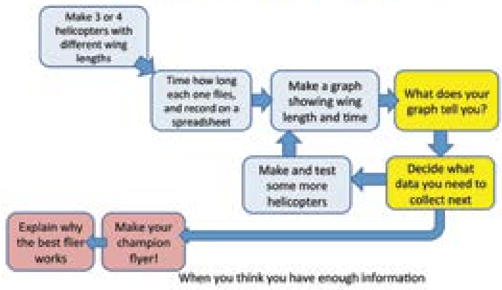
As with the parachute investigation, there are many possible variables that can be investigated with spinners: type of paper, wing length, tail length, number of clips, wing width, height of drop etc.

Pupils were given the motivation to trial and re-trial the variables by having the aim to discover the best spinner. They made the spinner and then set out to follow the Active Graphing procedure.

Making a spinner



Using Active Graphing for a spinner



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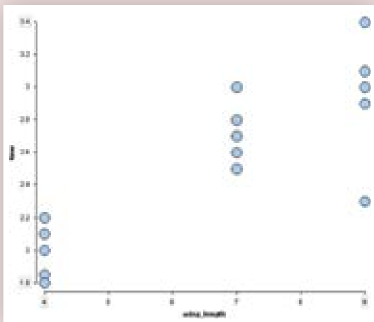

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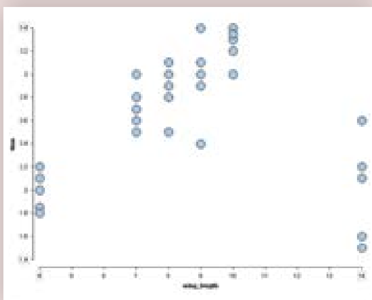

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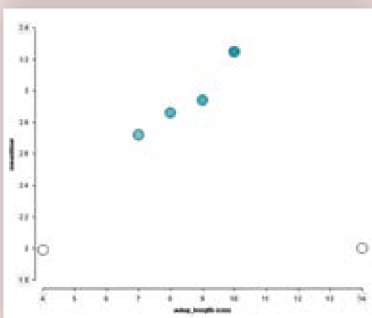
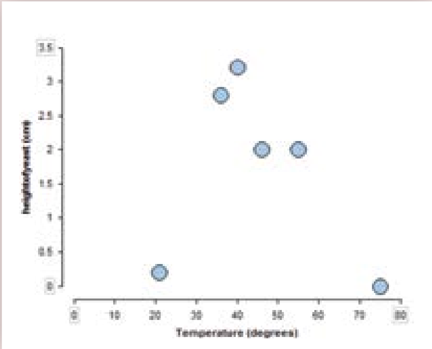


1. First trials investigated wing lengths from 4 to 9 cm. This data provided a pattern, which appeared to show that increasing length would give the best spinner.
2. As it appeared that a long wing would be good, the pupils tried increasing the wing length. However very long wings were not so good. Therefore they took more measurements in the 7 to 11 cm range. While there is a lot of detail, the variability makes the graph 'noisy'.
3. In this graph, they have using the mean of the time of flight. The graph is tidier, and it is easier to see a 'signal', but detail has been lost. By working through this process the pupils can appreciate the value and disadvantages of using a mean.

It is important to discuss both the mathematical and scientific implications of such an investigation. In this case pupils recognised that a big wing span which stays open and is flatish was good as it was slowed down by air resistance. The spinning process stops the wings flattening and becoming narrow and streamlined and thus falling fast as it is pulled by gravity.

Active Graphing: Investigating yeast

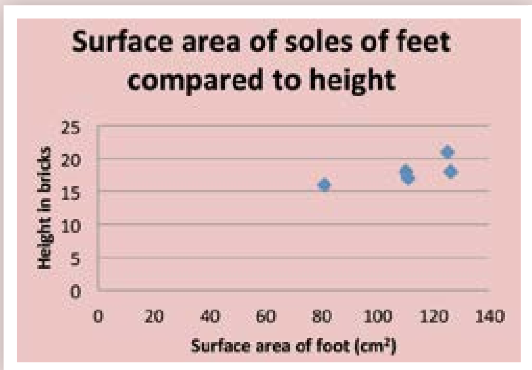
As there was not enough time to collect a lot of samples, teachers were provided with some data to start with (i.e. the Active Graphing process was started for them). They were asked to investigate the effect of sugar or temperature on the growth of yeast. Existing data was presented to the teachers as a starting point. They were then asked to find out the ideal conditions for growth of yeast. As the highest foam indicates greatest yeast activity, they thought the ideal temperature was about 40-50°C. They decided to explore this limited temperature range further.

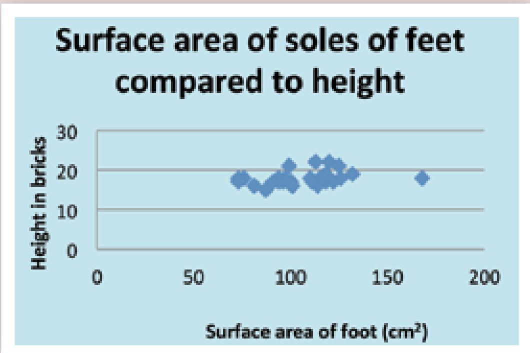


Looking for patterns

Talking about patterns can indicate areas for further measurement. In this experiment, after the initial results, pupils could see they needed to focus on the surface area of the soles of their feet in the range 50 - 200cm².

NAME	Foot size (cm²)	Height (bricks)
Jay	110	18
Joseph	125	21
Mia	111	17
Joshua	126	18
Abbi	81	16





Looking for patterns

Graphs provide one way of sorting data and looking for patterns. Other methods such as Venn diagrams, Carroll diagrams, branching data bases can be used with children of different ages. This data can be collected by the pupils in their investigations, but it is also important to use existing sets of data, to look for patterns that suggest hypotheses that can be tested.

It is useful to consider whether the results from a completed class investigation will be the same as results from another class. This is a way to introduce pupils to the use of large data sets which they might not have time to collect themselves. On-line data sets from other classes in the UK and other countries might also be used.

Are older people taller than younger people?

One class started by lining up with children by age. Their heights gave a visual impression that older people were taller for their class, but not always. They were then given data from different schools, different countries and different eras i.e. data from:

- 136 children born in California in 1928-9 and
- a Year 4 class in the UK collected in 1994

Both data sets contained data about gender, height and age. The pupils were then encouraged to use the data in a variety of ways to explore different interpretations of the question and the different variables (such as gender) and era. They were also encouraged to try to explain the patterns.

Investigating height and foot size

A class of 8-9 year olds investigated whether there was a relationship between height and foot size. This enabled them to use measurements of both length and area. The data was entered on to a spreadsheet on a computer giving practice in using ICT. The pupils were asked to identify their own personal information on the graph as a way of helping them to understand and use coordinates. The pupils also discussed the variability of their results with regard to sample size and quality of measurement.

Number of helium balloons to lift a person

During a Science Fair for parents, 10-11 year old pupils were given the challenge of finding out how many helium balloons would be needed to lift a person. They investigated the weight needed to balance a helium balloon stationary but above the ground. The pupils then used this data to work out ratios of weight to number of balloons, to work out how many balloons might be needed to lift different people.

Classifying and exploring the significance of shape

It is very easy to treat shapes in both science and mathematics is a superficial way. It is not enough to just name shapes and identify them in nature and man-made situations. It is important to investigate the properties of shapes. In science it is important to look at how and why properties of shapes influence how they act when forces act on them. Mathematics helps to provide a language to talk about why particular shapes occur in scientific contexts.

Leicester teachers were asked to make shapes from triangles, to sort and classify them, to identify the properties they were using to do so and to explain how they were classifying them. They then used these ideas and appropriate mathematical language in a variety of science investigations (see examples below).

Can you blow different shaped soap bubbles?

The teachers made different shaped bubble-makers out of pipe cleaners and investigated the shapes of the bubbles. They were challenged to make a square or triangular bubble and then asked to explain why they consistently got a shape like a sphere. However as the sphere was not perfect they were asked why not.

To help with the explanations, they were encouraged to describe a sphere – i.e. all points on the sphere are at an equal distance from the centre (radii). They were then helped to see that soapy material is 'elastic' and pulls inwards to the centre. The main force then is pulling towards the centre of the sphere. However the soapy sphere is not usually perfect as there are other forces at work e.g. wind and gravity.

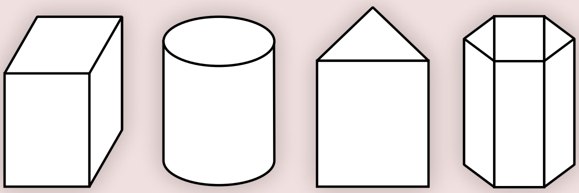
Investigating which shapes make a strong bridge

Finding ways of making a strong bridge using one sheet of A4 paper to span a gap of about 15 cm between two blocks and carry a weight of 100g helped teachers to identify triangles and cylinders for strong shapes.

Following the results of their investigations, the teachers were helped to understand why cylinder shapes were so good. A horizontal card will bend (or compress) easily if its opposite sides are pushed together horizontally. Once the card starts to bend it will buckle upward or downwards. If the card is folded at right angles along its length, it can no longer bend easily. A tube provides more strength than flat paper as it resists bending in any direction. Bundles of tubes are even stronger.

Investigating the shape of pillars for bridges

Classes of 12 year olds investigated the use of different materials and shape for bridge pillars. They tried different shapes and heights. They discussed the properties of the 3D shapes and why they thought some resisted a downward force more than others.



Area, Perimeter, Volume, Ratio and Proportion

The relationships between measurements of perimeter and area as well as volume and surface area are very difficult concepts for pupils to understand in mathematics. This is because they need to imagine two variables such as area and perimeter at the same time. Science investigations provide practical experiences to help them understand.

In order to understand why a small child might get cold more quickly than an adult and thus need more layers of clothing, why large sugar crystals dissolve more slowly than regular sugar, why penguins huddle together for warmth, or why elephants have such big ears, it is necessary to have an understanding of volume and surface area and how the proportions of these measures vary in different shapes.

It is important to encourage teachers and pupils to make both mathematical and scientific generalisations. Some 'rules' they might identify are suggested below.

Area and perimeter

- If you have a fixed area and change the shape, the perimeter changes.
- There is not a direct relationship between area and perimeter.
- The circle gives the biggest area for a fixed perimeter.
- A hexagon is the closest shape to a circle that tessellates.
- If we use only rectangles, the square gives the biggest area for a fixed perimeter.
- Irregular shapes will give a smaller area for a fixed perimeter.

Volume and surface area

- If you have a fixed volume and change the shape the surface area changes.
- There is not a direct relationship between volume and surface area.
- A sphere has most volume inside for the least surface area.
- If we use rectangular shapes, a cube has the most volume inside for least surface area.

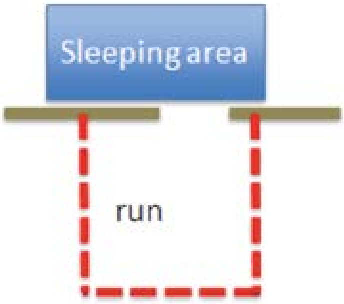
Biological shapes and organisms are usually economically designed. Therefore we find organisms that maximise area or perimeter / surface area. For example bee hives use a hexagon which has the maximum area for the shortest perimeter that tessellates. The bronchi and bronchioles in the lungs maximise the area for gas exchange by having many tubes with a lot of surfaces where gas exchange can occur. Similarly leaves are flat to maximise the surface for photosynthesis and transpiration.

Science contexts to explore the relationship between area and perimeter: animal enclosures

To help learners, it is helpful to keep one measure fixed. Then change the shape and investigate how the other measure changes.

1. A run for rabbits – fixed perimeter fence

In this investigation, the rabbits have a sleeping area, with an entrance through a low wall. The pupils have a length of flexible fencing with which to make a run for the rabbits outside the wall with the biggest possible area. Some 8 year old children measured the enclosure side lengths by folding a strip of paper and the area by counting the squares on the paper. They recorded the results on a spreadsheet to see how the area of the enclosure varied. Older 10-11 year olds were able to do the tasks at a more complex level by making use of scale (i.e. representing metres by cms on paper) to draw diagrams of the enclosures.



Part of the task can include raising the issue about the conflict between the interests of the animals and humans. If these rabbits are in a family home, children can easily access them by picking them up. Therefore a big pen is ideal.

However if the pen is at a zoo, is it better to have a shape where the rabbits are always close to the visitors where they can see them (or torment them!)? Is it better for the rabbit to be able to keep away from the visitors?

2. An expensive enclosure for gorillas – fixed perimeter of any shape

A different animal care issue can be raised with different animals. For example, teachers were challenged to investigate the shape of an enclosure for a gorilla. They were told that the gorilla needed special fencing for its enclosure as it could climb ordinary fences. However, the zoo could only afford 720 meters of this special fencing. They considered:

- What was the largest area possible?
- What would be best for the gorilla?
- What would be best for the people who come to see it?

Some teachers modelled their ideas on squared paper using the side of 1 square to stand for 10 meters. Others used a spreadsheet. The teachers were encouraged to provide a rule to explain the relationship between area and perimeter. The activity also stimulated a lively debate on the rights of keeping gorillas in zoos, the value of breeding endangered animals, needs of educating people about extinction and animal care.

3. A large enclosure for cheetahs – fixed area and flexible perimeter

In this investigation, the teachers were asked to explore possible shapes for an enclosure for cheetahs that need 4800 square meters. They were asked to consider:-

- The length of perimeter fence for each design
- What would be best for the cheetahs?
- What would be best for the people who come to see them?
- What would be most economical for the zoo?

4. Bird enclosure – fixed volume and flexible surface area

To enable the teachers to think about volume and surface area, they were asked to consider the design of a small bird enclosure which had 480 cubic meters of space, with a roof so the birds can't get out and wild birds can't get in.

Enclosures for different animals

Secondary mathematics and science teachers planned separate activities for their 12 year old pupils which enabled them to link mathematics and science, despite the fact that they are unable to teach the pupils together. The school timetable requires pupils to study 'area' in mathematics lessons early in the year. In these sessions, pupils will be given different animals to research with regard to their habitat needs. They will then investigate the area of suitable enclosures using a fixed length of fencing. The pupils will make posters of their findings. Half of the posters will be displayed in the mathematics rooms and half in the science rooms.

Later in the term the science curriculum requires pupils to study 'variations in habitat'. The display of posters will be used to recap what has already been done before further studies and investigations are carried out on animal variation. The work will also be recorded in poster form. Again half the posters will be displayed in the mathematics rooms and half in the science laboratories.

The two secondary teachers say that work on the Fibonacci project and this process of shared planning has altered their perceptions and practice. They hope that the posters will influence other staff in their respective departments.

Modelling animal enclosures for a farm

A class of 13 year olds were given information about the area needs of different animals and fixed totals of area and finances available for fencing. They were asked to investigate different ways they could populate the farm with animals.

Science contexts to explore the relationship between surface area and volume: heat insulation

As indicated earlier, there are many opportunities to explore the relationship between surface area and volume in science investigations. These investigations can be done with very young pupils by putting the investigation to a story or very familiar context and making sure that the mathematical demands are within the pupils' abilities. The investigations can be made more demanding as the pupils get older by adding the variables to be considered, using more complex instruments and making the task more open-ended. The next four investigations all explore the relationship between heat loss with variable surface area / volume with different contexts and level of demand.

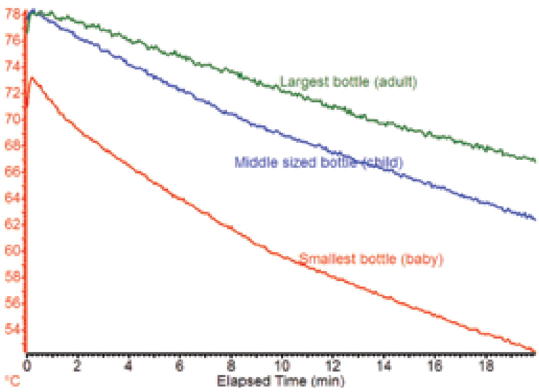
1. Goldilocks and the Three Bears' bowls of porridge

Very young pupils can investigate heat loss from different sized bowls. There are different versions of the Three Bears story where Goldilocks tries 3 bowls of porridge to find the one that was warm but not too cold. In some stories Dad's large bowl was too hot, Mum's middle-sized bowl was too cold and baby bear's small bowl was just right. In other accounts Dad's large bowl was too hot, Mum's middle-sized bowl was too hot and baby bear's little bowl was just right. One class of 5 year olds investigated to discover which story format was scientifically valid.

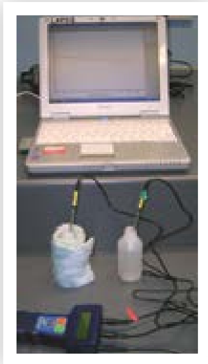
To simplify the measuring 1, 2 and 3 packets of porridge mix was made up with water. Thermometers were placed in the bowls so that the pupils could directly compare the change in height of the red fluid in the thermometers.

2. Should babies or young children be wrapped up any differently to adults?

Teachers were asked to investigate whether babies lose the same, more or less heat as adults when sitting out in the park. They used bottles of different sizes to represent different sized people. They found that because there is a greater ratio of surface area to volume babies lose heat more quickly. From this they went on to investigate what sort of fabric is best to wear in cold weather and whether it is better to have layers of clothing or one thick layer.



Baby, child and adult

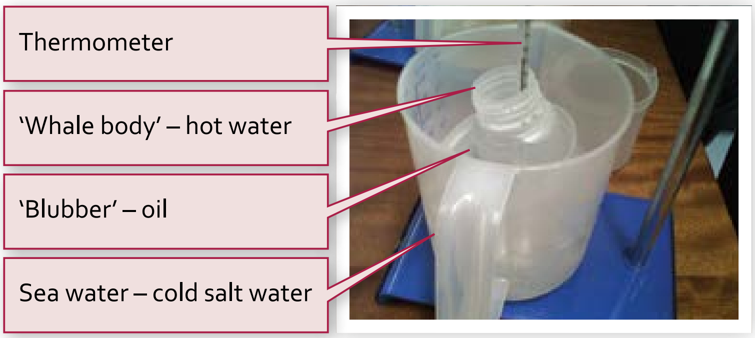


Baby with and without blanket

Layers of blankets

3. Why are whales so big? Does a layer of blubber make a difference?

Like all mammals, whales are warm-blooded. A killer whale's core body temperature is about 36° – 38° C similar to humans. Living in the sea is particularly difficult for marine mammals, because water conducts heat about 27 times faster than the same temperature of air. Teachers were asked to investigate whether there are differences in heat lost between small, medium sized and large whales. Just under the whale's skin is a thick layer of blubber, composed of fat cells and fibrous connective tissue. It can be 7-10 cm thick. It helps to streamline the body. Teachers were asked whether it also helps with heat loss. They used oil on the top of hot water as 'blubber'. This investigation is similar to comparing the volume/surface area of babies and adults, but less familiar and requiring more complex equipment.



'Whale' with and without blubber

4. Insulation properties of take-away disposable coffee mugs

A collection of different sized mugs: tall, medium and short from major take-away companies was made. Teachers were asked to collect data on a spreadsheet about different companies' mugs with regard to their heat retention. They explored several variables including material, volume, surface area and heat loss.

This task not only involves a science investigation, it also required the investigator to work out a way to measure the surface area of the mug with sloping sides. One way is to open up the cup and use squared paper or squared acetate to count the cm^2. Another is to create a formula for a spreadsheet such as average of circumference of the bottom and circumference of top x length of sloped side which is a close approximation.

Investigating insulation in Antarctic animals

A class of 9 year olds investigated both the effect of 'blubber' on heat loss as well as why penguins huddle.

They used a simple method of using oil to represent the blubber on the top of beakers of warm water. They set up three beakers: one without oil, one with a little oil and one with a lot of oil. They used a data logger with three temperature probes attached. This enabled them to constantly see the changes in the water temperature. They could see the faster drop of the temperature in the water with no oil. They also collected the data from thermometers and produced their own line graphs.

They also looked at a YouTube video on penguins huddling, then used bottles of warm water to 'model' the penguins. Within half an hour, they were able to see that the penguins on the outside became much colder. (This explained why penguins constantly keep moving to change their position so all penguins have time in the centre and outside.) Again both data loggers and thermometers were used.

The teacher reported that these activities were very valuable in helping pupils understand and use line graphs.

Other investigations relating surface area and volume

Insulation is not the only scientific conceptual area where ideas about area and volume are important. Rates of dissolving and chemical change are often influenced by these factors.

For example, a class of 13 year olds were investigating rates of reactions of Alka-Seltzer in water and chalk in acid. The pupils could not explain why the rate of change differed with differing size pieces of solids. They appeared to have little understanding of surface area despite having a reasonable grasp of both area and volume. Their science teacher knew that pupils found ratios difficult. Therefore she borrowed multilink cubes from her mathematics colleague to support the pupils' visualisation of both volume and surface area. Using a 4x4x4 cube she asked the pupils to calculate surface area and volume by counting. They then made different size cubes by using smaller cubes. The pupils recorded the volume by counting the cubes and surface area by counting the external faces of the cubes.

This led to discussion between the mathematics and science teachers about how to support pupils' understanding of both volume and surface area. They then developed an activity involving the dissolving of jelly for 12 year old pupils. Again the multilink cubes were used to try to support understanding of the surface area to volume ratio in both subjects.

Models in science and mathematics

We use models in science to focus on structures and phenomena to try to express and understand science ideas. These models can range from simple animal puppets and plastic model creatures for very young pupils to abstract equations such $E=mc^2$.

- Models are a simplification of reality and so will have limitations.
- Different models can address different aspects of the same phenomena.
- Mathematical models can be theoretical or based on data collection.
- There are different purposes of models:
  i) Explanation or structure of what is happening in reality;
  ii) Prediction; and/or
  iii) Problem solving.

To get a good model we need good observations. They also often involve considering sample size and variables. Then they have to be tested.

A progression of activities

Teachers at the University of Leicester explored ways of developing the idea of mathematics in science models.

1. Early activities with pupils

Pupils might look at a range of models of insects to list what features are correct and incorrect. For example a class made model ladybirds after carefully observing them. Their ladybird models were red with black spots and had antennae. However they were far bigger than the real animal and of course their models were not alive and could not feed or reproduce. By identifying where their model was correct or not, the pupils learnt more about ladybirds as well as being introduced to evaluating models.

2. Models used to explain and predict movement in space

At the University of Leicester Fibonacci teachers considered models that could be used when studying Space. They considered the merits of traditional stories of creation; different designs of orreries; creating scale models of the solar system using seeds; role play activities showing the movement of the moon around the Earth and how seasons occur; and on-line interactive models.

The teachers were also introduced to the navigational need, in the past and currently, for a mathematical model that would not just explain observations, but allow people to predict the movement of the planets. They considered the ancient idea that the Earth was placed in the centre of the universe with stars and planets moving in circular orbits. As advances in technology allowed better observations the mathematical model based on circles did not give predictions that fitted what astronomers saw. Copernicus' model represented a radical step forward as it changed the model to place the Sun at the centre, and treated Earth as a planet. In his model the moon rotated around the Earth, but all movement was circular. This model still did not predict the movement of the planets in ways that matched systematic observations made with better instruments. Later Kepler analysed detailed observations and tried to fit many different complex mathematical models to the data. Eventually he found a simple model which fitted: the orbits of the planets were not circles but ellipses. This model is mathematically elegant and also worked efficiently.

3. Creating mathematical models in school

While pupils can hear the stories of how models were developed in the past, creating such a complex model is beyond them. However investigating how to develop simpler models can give pupils the ideas of the process.

Developing a mathematical model for a game at the school fete

The teachers were asked to create a simple game which involved throwing bean-bags into targets with scores from 1-10 on. A player would win a prize if they scored more than an unknown score. Teachers were asked to assume players pay 10p per go. They were asked to work out a model that enabled the school to make a profit, but still attracted players who wanted to try. The teachers could then state the score needed to win and how much the prize would be.

An important element of the activity was that the teachers were asked to test their model by playing the game. Initially they had to start with 10 players at 10p. They were asked if they made a profit. Then they were asked to continue with more players to consider the effect of increasing the sample size.

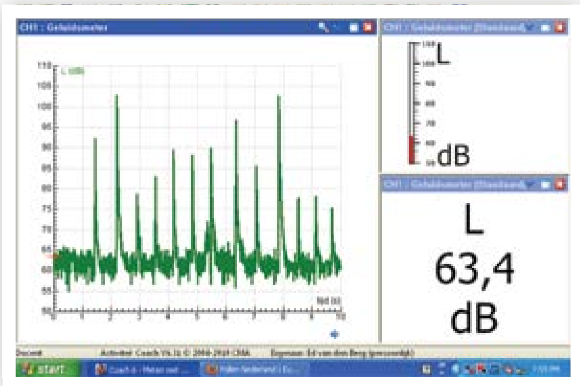
Use of ICT to develop science inquiry

Data logging to support graphical understanding and science concept development

Making line graphs in science experiments in primary school by hand is tedious and difficult for young pupils. Data logging reduces the mental and physical effort children must invest in constructing the graph so that there is more time and attention for interpretation (Newton, 2000). There is evidence that data logging (sensor) activities can have positive results in primary school and that line graphs can be used productively with 10-11 year olds (Nicolaou et al., 2007), perhaps even below (McFarlane et al., 1995).

Traditionally many teachers start the topic of line graphs by *constructing* graphs. That is difficult! Now that we have computers and sensors and know a bit about children's learning, the Netherlands team has found that it makes more sense to start with an intuitive approach to understanding line graphs. Science investigations provide many opportunities for seeing line graphs produced as part of an investigation.

Sound, light and temperature sensors used in the Netherlands



Typical display on the computer

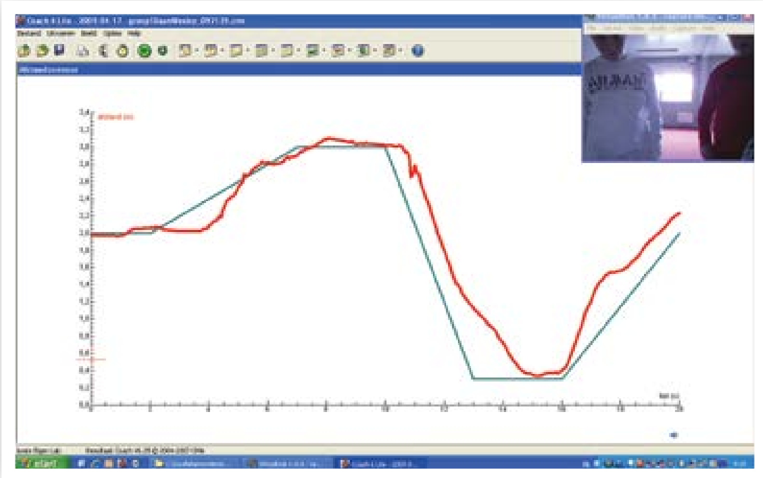
Early intuitive activities to introduce line graphs with data loggers

The Netherlands teachers have used a distance sensor to introduce interpretation of line graphs. Individual pupils stand in front of a distance sensor and move backwards and forwards in front of it, while watching the graph produced. The pupil then tries to replicate an existing graph. Teachers in Leicester used a sound sensor in a similar way. They asked the class to make a quiet sound, followed by a loud sound and watch how the graph changed. They were then shown a line graph as a 'musical score' to create changing sounds.

This type of activity helped the pupils to appreciate that the graph is a 'story' of change.

- Horizontal line – no change
- Point where angle changes – something different happens
- Sloping line shows an increase or decrease
- A steep slope show that the change is happening quickly

Distance sensor



Pupil attempts to replicate an existing graph in red

Greater understanding of line graphs through using sensors

Van den Berg (2009) carried out a small scale research study in the Netherlands on 27 10-11 year old pupils and 13 11-12 year old pupils. They used a distance sensor for 20 minutes and a temperature sensor for 20 minutes. A video/audio recording was taken of the learning process. Pupils were given a pre and post test on their understanding of the meaning of the angle and direction of line graphs. There was a noticeable improvement, particularly with the older 11-12 year old pupils after the activity (see table below).

Movement as detected by sensor	*10-11 year old pupils (%)*	*11-12 year old pupils (%)*
Direction	41	81
No movement	75	100
Time	55	90
Speed	41	77

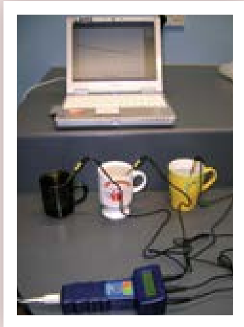
Table: Percentage of pupils with correct descriptions of the graph produced by a movement sensor

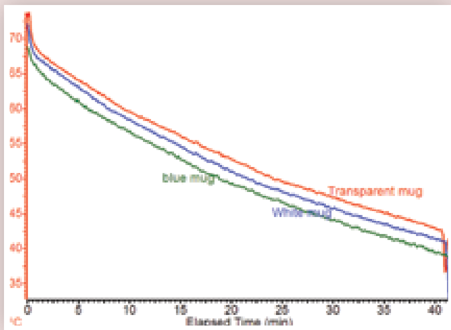
Half were also interviewed 5 weeks later. These pupils were asked how they would use a sensor in a new situation, (i.e. to determine the winner in a clapping contest). 60% of the 10-12 year old children had acceptable solutions although pupils of different ages tended to have different approaches. The 10-11 year old pupils (grade 5) mainly used distance between peaks in the graph (small distance showing fast clapping) while the 11-12 year old pupils (grade 6) tended to use frequency of the peaks per time interval.

Typical science investigations using data loggers to produce line graphs

Which mug keeps a hot drink warmest?

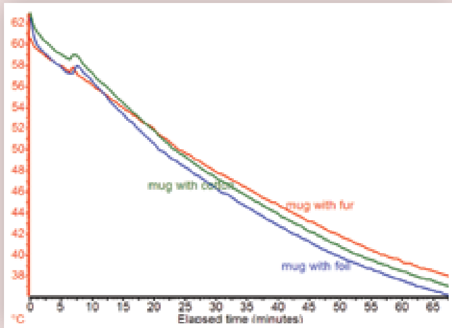
Pupils were asked to predict which of 3 mugs would keep hot water warm the longest and why. They then used use 3 temperature probes with one in each mug.



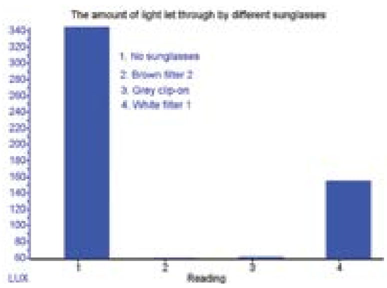


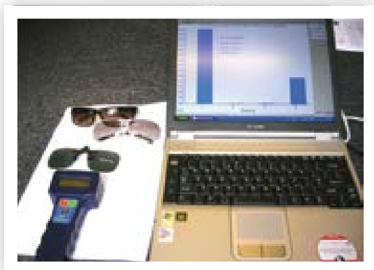
What material would make a good insulator for a mug: fur, foil or cotton?

By seeing the graph being produced during the experiment, the pupils could concentrate on explanations. They agreed fur was very good because it traps air in it. (Air is a poor conductor of heat so insulates well.) However, they were surprised that metal did not keep the heat. They were then prompted to think how hot metal spoons get when stirring hot soup so realised metal is a very good conductor of heat.



Data loggers used to produce block graphs





Data loggers can be used to produce block graphs as in the case of the pupils who investigated which sun glasses would protect their eyes best. In this case pupils took discreet data and compared it. The use of the data logger again enabled them to focus on the results of the investigation as they did not have to spend a lot of time producing a hand drawn graph. They were also able to talk about when a line graph and block graph are appropriate. Of course this does not mean that pupils should never produce hand-drawn graphs. The teacher needs to be clear what the objective of the lesson is – understanding science concept or mathematical skills.

Using sensors in complex investigations

Investigations supported by ICT can be used by older pupils to carry out real-life inquiries with and for the local community. For example such projects were developed in the town of Orastie (in the Transylvania region of Romania) and in the town of Eforie Sud (on the Black Sea coast). Both teams were assisted with the required technical means by the Centre for Science Education and Training, the Romanian national coordinator of the Fibonacci project.

Preparing a noise map of Orastie town

As per EU's directives major urban locations are asked to have noise maps by 2015, in order to evaluate and monitor noise pollution. Members of the "Little Investigator" Physics club of "Aurel Vlaicu" National College, under the supervision of Physics teacher Mrs. Giurgiu Margareta, measured the noise level in several cross road points at different hours of the day, by using a Eurosens data logger and a calibrated noise sensor. The results were marked on the town map. A paper describing this investigation and communicating its results was awarded the First Prize in 2012 at a school science contest at county level.

Noise map of the Orastie town prepared by high school students as part of the Fibonacci project.

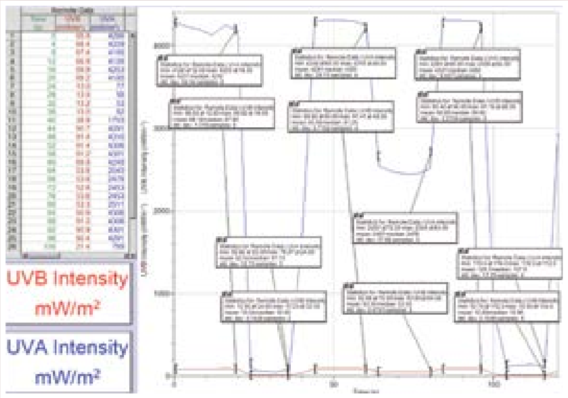
Efficiency of different UV radiation protections

This investigation was carried out by a team of middle school students from Grup Scolar 'Carmen Sylva', Eforie Sud, under the coordination of Physics teacher Mr. Florin Serbu.

They investigated:

- the attenuation of solar UV-A and UV-B radiation by different brands of sun glasses;
- the UV radiation absorption by various textiles and leaves of different trees species;
- the eficiency of UV radiation protection provided by several sun protective loations.

For the e-measurements the team used UVA / UVB Vernier sensors linked to the LabPro interface and controlled by the LoggerPro software.



The UV radiation intensity measured for several textile materials

Other ICT devices

Other ICT devices are important tools to support investigative science. Many classes use computer word-processing, statistical, graphical and spreadsheet packages; digital and video cameras; voice recorders; digital microscopes etc.

The Greenwave project

The Greenwave Project as part of Fibonacci involved classes all over Europe noting the first signs of spring for a variety of specific species (e.g. horse chestnut tree, frogs and swallows) used ICT. Pupils recorded their sightings on computer and could also up-load photographs. Data from all over the Fibonacci countries was shown on maps so that pupils could plot how spring moves across the continent.

This cross-curricular activity was very successful with over 80 Romanian classes engaged in the project. They, like other pupils, designed and built apparatus used in meteorology investigations, to carry out measurements on weather and to run observations on the first signs of Spring. However the Center for Science Education and Training - CSET, the coordinator of the Romanian participation to Fibonacci, decided to further foster inquiry science education by adding an ICT component. The European "George Coşbuc" Middle School from Baia Mare (coordinator: Mrs. Ana Puşcaş, teacher of Physics), in the Northern part of the country, acted as pilot school and was offered a data logger with a temperature sensor, linked to a laptop through the USB port. The objective of this extension was to familiarise students with the use of automatic equipment employed for weather monitoring and to introduce them to graphs and their interpretation. The student age covered the 10-13 years span. Following these investigations, the school designed its own web site dedicated to this project (http://46classprojects.wikispaces.com/ and http://photopeach.com/album/1368wwq).

Robot based cross-curricular activities

The Fibonacci team in Romania has also developed robot-based cross curricular activities. A more complex approach in teaching science at high school level was demonstrated at the National College "Alexandru Ioan Cuza", Galati, Romania (coordinators: Mrs. Catalina Stanca, teacher of Physics, and Mrs. Daniela Ilie, teacher of ICT). Starting from 2010, the Center for Science Education and Training (CSET) established a 'Robots Club'. Some LEGO Mindstorms robot sets were donated. The sets also included several sensors from Vernier Software and Technology, sensors which can be controlled by the LEGO programmable unit.

'A New Earth'

Romanian pupils were given the scenario that in the near future, Planet Earth would become almost uninhabitable. The pupils were asked to locate a planet able to support human life and which could be populated with colonists from Earth. Following some study, pupils 'discovered' the imaginary Gliese 581 g planet, situated near the middle of the habitable zone of its parent star. It was a rocky planet with favorable atmospheric conditions making possible the presence of liquid water at its surface. The pupils were asked to send a robot to this planet to evaluate the possible living conditions.

Robots were programmed to operate in pairs, one of them gathering data and the other one analysing the information and communicating via Bluetooth. Robots were assigned different jobs in order to evaluate the conditions on this planet: rock collection; assessment of the acidity of and dissolved oxygen in various liquids found in volcanic craters; measurement of optical radiation at the planet surface, including the UV components; and estimation of the magnetic field.

One outcome of the program was shown at the National College "Alexandru Ioan Cuza" where primary school students were introduced to robotics by their high school peers. A video and further information can be found at http://education.inflpr.ro/ro/Fibonacci1.htm

Developing links with literacy

We are using the term 'literacy' as the ability to talk coherently; read for knowledge; write coherently; as well as think critically about the written word. This means that some pupils are working in a language that is not their home language. There should be a close relationship between literacy and science. Competence in the former provides the tool for effective scientific communication. Science investigations provide a stimulating and relevant context to inspire pupils to improve their literacy skills.

- Speaking and listening
  To be successful learners of science, pupils need to be given the opportunity to speak clearly and effectively in order to explain their science using science language. They need to explain quite precisely what they are thinking and doing. Children working on practical science investigations also need to work together co-operatively, discussing meaning, intentions and ideas and so need the listening and interpretive skills that are fostered in literacy sessions.

- Reading
  To research their science investigations, pupils need the skills to access information in a range of forms including books and the internet. By reading pupils can compare their ideas with those of others, gain ideas for investigations and for further work. Being a critical reader enables the pupil to evaluate texts both for their usefulness and their reliability as unbiased sources. Reading is also a necessary skill to initiate a search using computer data systems, many of which rely on precise use of vocabulary to narrow the search.

- Writing
  To present their findings to others, children need the skills to write accurately in a variety of forms such as notebooks, reports, newspaper articles, poetry that suit the audience they are targeting.

It is easier to make links between the two subjects when the same teacher takes both the science and literacy lessons. However science and literacy teachers, in other situations, can achieve similar advantages for both subjects by collaborating in their planning. The teacher educators at the University of Leicester have been developing a variety of strategies for enhancing the links between literacy and science. Educators in Luxembourg, Estonia and Leicester have also been developing additional strategies for supporting teachers and pupils who speak a home language which is different from the language of the science classroom.

Linking science investigations and literacy in a monolingual classroom

By using scientific texts in the literacy class, the time available for science can concentrate on the practical investigation. A text can be introduced and developed for literacy skills. This text becomes the context for an investigation. The results of the investigation are then written up in the original genre using the new literacy skills. The practical work usually enthuses the pupils who are more motivated to write or communicate.

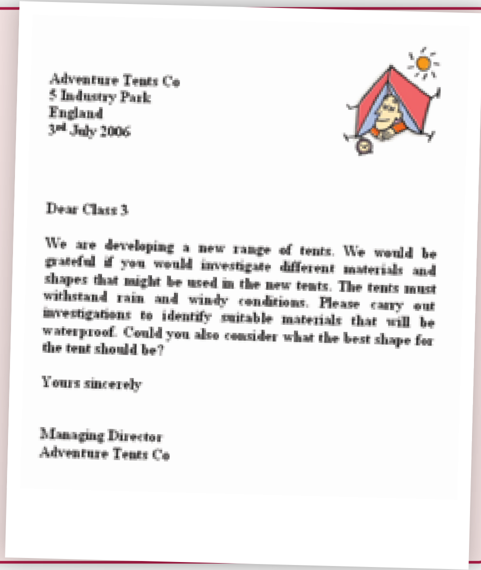
Literacy	The fiction / non-fiction can be read and analysed for language objectives		Children use their new science language or experience to write in the focus genre.
Science activities		Science session practical time optimised	

The type of text can be:-

- Fiction - myths and traditional stories
- Letters, emails, fax
- Persuasive text
- Non-fiction science texts – e.g. reports, explanations
- Autobiographies and biographies

Letter as a starting point

1. The class were given a letter as part of their literacy lesson to learn about how a letter should be set out.
2. During their science lesson they carried out an investigation to test materials for waterproofness.
3. In a later literacy lesson they wrote a letter to the 'Managing Director' with their results.



Adventure Tents Co
5 Industry Park
England
3^{rd} July 2006

Dear Class 3

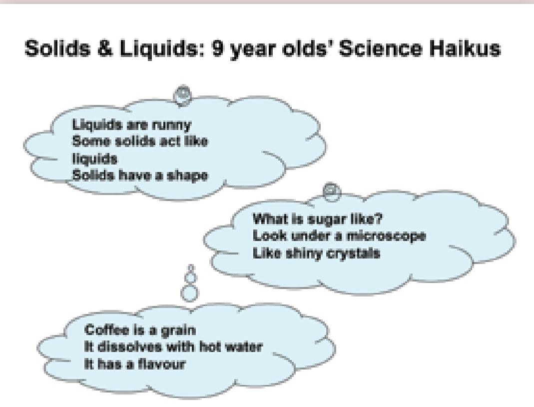
We are developing a new range of tents. We would be grateful if you would investigate different materials and shapes that might be used in the new tents. The tents must withstand rain and windy conditions. Please carry out investigations to identify suitable materials that will be waterproof. Could you also consider what the best shape for the tent should be?

Yours sincerely

Managing Director
Adventure Tents Co

Poetry: Haiku

Poetry and science can be linked. As one teacher pointed out, '*You need to know the science before you can be creative enough to write poetry*'. Several Leicester teachers successfully used haiku with their pupils. One teacher has found them a particularly effective way of enabling her 8-year-old pupils to summarise their science ideas and for assessing them. One session at the Cross-Curricular Seminar in September 2011 was devoted to exploring how poetry and magnetism might be linked. During the session participants were asked to use investigations of magnets and observations of magnetic fields to produce haiku.



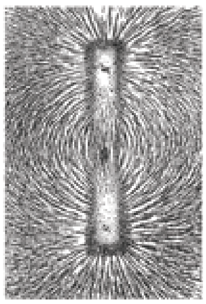
Teacher's Haiku

Iron filings sit
Grey and dusty, old man's beard
Suddenly they jump!

Spiky filings flow
Like a hedgehog moving slow
Into a round ball

Specks of iron rush
Like a dog chasing its tail
Twisting and turning

Spiky filings move
Ripples in the plastic bag
Swirling and whirling



Linking science investigations and language in a multilingual classroom

In a number of the countries that took part in the Fibonacci Project, the language of instruction is not that of the pupils and, in some cases, not the teachers' home language either.

Pupils speak a different language from that of the language for instruction

This is a very common situation in Leicester Fibonacci schools. This has motivated teachers to make greater efforts to link their literacy and science teaching. Alongside this pupils work in pairs or groups where they are given plenty of time to talk to their peers. Groupings are carefully chosen so that pupils can speak in their home language during the investigation to promote thinking and formulating ideas, but they are required to present their findings in the main language. Writing frames are used that provide a structure for the investigation. Visual aids, word banks and bilingual dictionaries are also used to help pupils become independent during an investigation.

Notebook structure

The Netherlands team found the use of notebooks can be helpful to provide structures for an investigation. Headings might include:

- My question (question)
- Today we want to find out (problem)
- I think that... will happen because.. (prediction)
- I saw that (observation)
- Today I learned (conclusion)
- I wonder (next step)

Teachers and pupils speak multiple languages in the classroom

The Fibonacci educators in Luxembourg have concentrated on supporting teachers in focusing on the learning of languages alongside science, as the language situation in Luxembourgish classrooms is complex. Luxembourg's schools are officially multilingual, and students learn in three languages at the primary level: Luxembourgish, German and French. In addition to the complexity inherent in learning multiple languages, the number of immigrants who speak many different languages continues to increase.

When there are multilingual backgrounds of students, there is a variety of considerations for the role of language for the learning of science. In Luxembourg, this is further complicated by a multilingual curriculum, with Kindergarten taught in Luxembourgish, most subjects starting in first grade are taught in German, and French is introduced in second grade. The Luxembourg team has worked with teachers to explore a variety of techniques, and to provide support to the teachers in sharing ideas that work in their own classrooms. Although the language of instruction for science is intended to be German, most of the Luxembourgish Fibonacci teachers have indicated that they prefer to teach science in the Luxembourgish language. Teachers have stressed that this provides the opportunity to first expose children to new science concepts and processes before introducing vocabulary in German. Therefore Fibonacci educators have collaborated with teachers to develop strategies and pedagogical techniques to support teachers in this approach.

Small group discussion in the home language before sharing ideas in a common language

One pedagogical technique for multilingual classrooms is to support pupils in using the language they are most comfortable with during small group interactions, and then sharing ideas with the whole class and the teacher in German. In this way, pupils are able to clarify and talk about their questions and ideas in science in a language that they are fluent in, while still developing their science vocabulary and conceptual fluency in German.

Personal pupil journals in their chosen language

Within a multilingual context, teachers can integrate science and language processes through student-designed journals ('Forscherhandbücher') which pupils produce on their own. In this kind of journal pupils describe their explorations including their questions, suggestions, observations, and experiments in their own words. They complete them using their preferred language, and add drawings and diagrams to enhance the expression of ideas. This is particularly useful for pupil documentation if they cannot yet express themselves in writing in the new language.

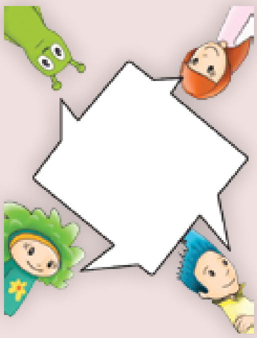
Open-ended science activities

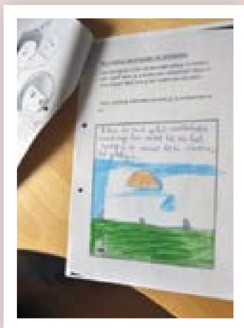
In addition to these specific techniques for supporting languages and science content, an overarching strategy that has been successful is the use of open-ended activities. Teachers have taken an activity or series of activities that allows flexibility. In this way teachers can take account of their curriculum requirements and the needs of the pupils.

Open-ended science activities: Using a film as a starting point

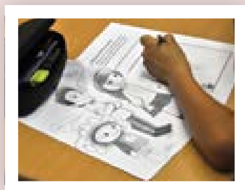
One school wanted to focus their work in the Fibonacci project on the topic of sustainability. The Fibonacci professional development team supported teachers to align their work in sustainability with inquiry-based processes and skills, and collaborated with the teachers to adapt an existing curriculum plan to their needs.

The teachers and the teacher educators selected an educational film 'Eliot and the Treehouse Gang' as the starting point for thinking about the complex issues of sustainability. This film was produced by Ina Schneider and Dr. Andrea Teuchert (http://www.3brillen.de/). This material utilises a cartoon-film as a basis to engage students in considering multiple perspectives to solve a hypothetical community-based sustainability challenge. In this film, Eliot, a cartoon character, and three children deal with a complex problem in their neighbourhood. As they work to address the problem in different ways, viewers are introduced to the three pillars of sustainable development: the society, the environment, and the economy.





The open-ended nature of the film allowed for adaptation and elaboration. The teachers worked together to develop a variety of ways for pupils to engage in the activities stressing the three perspectives, with appropriate connections to the curriculum and teaching material adapted to suit a variety of languages.



Developing links between investigative science and other subjects of the curriculum

Mathematics, ICT and literacy are all needed as means to communicate about science investigations. Therefore it is important to make effective links between them. However to make science relevant in society, investigations need to be given a context. Many other subjects in the typical school curriculum can provide a range of varied and stimulating contexts.

Geography and history

As geography and history involve studying the society of the present and past, they provide many scenarios that raise questions that can be investigated scientifically. It is important for experienced scientists to consider science phenomena in different parts of the world as well as the past. Solutions for current scientific problems may be solved by knowing about what happened in similar situations in the past and other geographical locations. For example, the current decline of bees may be due to large agricultural monocultures. Therefore, methods of mixed cropping used in the past and in areas of Africa and South America may provide solutions. Similarly looking at past methods of harnessing wind or water may help to reduce excessive dependence on fossil fuels that promote global warming. Plants and medicines used in the past and other cultures may provide a way to cure illnesses.

Pupils can use past and current context as a basis for their investigations. By focusing on developing science investigative skills, pupils can carry out the investigation at their developmental level. (This is less easy when linking mathematics and science where concept development in the two subjects is developmental. For example children need to understand simple electrical circuits before bulbs in series and parallel and appreciate addition of numbers up to 10 before numbers to 100.)

Why was wool a good fabric for the Romans to use?

During a study about the Romans, pupils realised the people wore wool. The teacher asked them to investigate why wool was used. They discovered from their reading that the northern European climate and vegetation suited sheep. They also found that the people had the technological knowledge to use fleeces. They then investigated the properties of wool compared to other fabrics to see if it had particular value. They found that wool was a good insulator and resisted water.

Which vegetables are suitable for dyeing fabrics?

Viking clothes were made from linen or wool which were dyed. Vikings produced blue, reds, yellow and purple from plants. Leicester was and still is a centre for clothes and has a dyeing industry, where dyes are tested and new colours developed. Pupils investigated whether different vegetables such as red cabbage, parsley, spinach, turmeric, tea, coffee grounds etc would make good dyes. Groups also investigated factors that made dark colours; and the difference between natural and non-natural fabrics.

Developing expertise over time

A cross-curricular approach has many advantages. Children are taught knowledge and skills in a holistic way in a context that is meaningful to them and more memorable. Learning is easier because it is less disjointed and more relevant. Children are enabled to use similar skills in different subjects. This helps them to understand and use these skills. Children can appreciate the contexts of their learning and so are more able to apply learning to their lives and develop a wider interest in the world. Language of the context is the same in each subject, making it easier for pupils who speak the home language as their second language to understand skills and concepts being covered.

However, it is important to ensure progression and continuity of skills and knowledge in all subjects. Relating a limited number of subjects, for example science with only one or two other subjects, makes monitoring coverage and progression manageable. It is important to identify the short-term and long-term objectives of each subject before the series of investigations or topic. This gives a structure for assessing pupil progress. It also enables actual coverage to be checked, as one of the risks of a cross-curricular approach is that one subject is overemphasised in response to pupil enthusiasm and interest, to the detriment of the objectives of the other subject. A post-topic review gives a second chance for adding activities when concepts and skills have not been covered.

Changing from the current, rather directed, single-subject approach to a more flexible creative approach takes time. Lack of experience of teachers (and schools) in using a new pedagogy is an issue. Some teachers may not be enthusiastic. Others may lack confidence and all will need professional development. 'Rethinking' and rewriting plans takes time. It is likely that current organisational practice / timetabling may need changing to support a cross-curricular approach. Achieving consistency throughout school will need support for the management and ongoing professional development.

Individual teachers need experience and support in developing an appropriate cross-curricular approach. Research based on the Pollen Project[6] indicates that change to a practical investigative science approach in the classroom requires the teacher to develop confidence in both science knowledge and pedagogy. This can take several years (Jarvis, Pell and Hingley, 2011). In the case of linking two subjects, the teacher needs confidence in both subjects. Therefore schools need to expect to plan to make changes over several years.

This process appears rather daunting but it is well worth doing for both teachers and pupils as can be seen from the experience of two teachers from Nantes.

[6] http://www.pollen-europa.net

Long term development of a cross-disciplinary approach in Nantes: Water management in the Loire estuary

Two teachers (one biology and one technology specialist) from a secondary school in Nantes set out to work together over several years on a new common topic that had relevance to their pupils. They had already an understanding of Inquiry Based Science Education (IBSE). A scientist, experienced in teachers' training in IBSE, then worked with both teachers for a whole year, before and during each session of the collaborative topic. A post-graduate student engineer was also present. The teachers developed an inquiry-based approach which also improved 12-13 year old pupils' learning in biology and technology. The collaboration involved the teachers sharing how the term 'inquiry' was understood in each of their disciplines. The content and development of the module set out to address the needs of each subject.

The teachers worked on a four month module based on the water management in the wetlands of the Loire estuary. This module explored the real problems that occur in estuarine areas (tidal inundation where sea water flows into the river causing sediment flocculation with salt and silt deposition) and its consequences requiring management of water in wetlands at St. Nazaire, France.

The module started with a general question "Why should we study the silt?". Pupils did a literature search on the nature of the river Loire. All pupils recorded their ideas, and then performed an Internet research. Subsequently pupils had a field visit with the territory's experts in order to learn about the water system, agriculture and biodiversity. After several sessions thinking about how to avoid flooding or draining of the marshes, pupils agreed that a network of channels and valves for regulating the water was needed.

Pupils were given a photograph of a valve to consider how it worked. They were then challenged to invent a system that could open and close a valve. Pupils presented their inventions; compared the advantages and disadvantages; and reviewed their ideas to take account of real constraints such as whether the lock keeper could operate the proposed heavy valves. This was solved by the idea of a gearing system. Later sessions focused on the formation of silt and its movement in the Loire. Pupils considered the influence of salt on the creation of the silt.

Throughout this process the biology teacher dealt with all issues related to living things while the technology teacher dealt with technological objects (valves) and the use of computers as a communication.

The pupils took a real pleasure working in an inquiry approach and became increasingly autonomous. They quickly recognised the stages of the inquiry process and appreciated the various complementary expertises of teachers, researchers and students. They were able to realize that knowledge varied depending on the person and that this factor did not preclude a common scientific approach.

This joint work was very rich for pupils, but it was also very valuable for teachers. It helped them break down barriers between disciplines around a unifying theme. Furthermore, it allowed the teachers to compare their teaching, and enrich their disciplinary practices. The teachers said that it allowed them to consider the implementation of IBSE at any level and in any discipline. It allowed them to stand back from their practice which in the past was too often tied to the discipline.

By working together in a cross-disciplinary context, and in collaboration with a scientist, every teacher had a framework to analyse his or her classroom practice, exchange expertise with a colleague, which contributed greatly to professional training. Pupils discovered the complex aspect of their surroundings. The pupils felt that the teachers had explored the topic "at the same time" (or at least they were also seeking to understand more the subject) and this helped to motivate them. The teachers had not only gained pedagogical training, they also experienced a small "research" project that has influenced their practices. These experiences have motivated the teachers, as well as the pupils, and they are motivated to extend the activity in following years.

Conclusion

Cross-curricular science involves embedding science investigations with one or more other subjects.

- Children are taught knowledge and skills in a holistic way in a context that is meaningful to them and more memorable.
- Learning is easier because it is less disjointed and more relevant.
- Children are enabled to use similar skills in different subjects. This helps them to understand and use these skills.
- Children can appreciate the contexts of their learning and so are more able to apply learning to their lives and develop a wider interest in the world.
- Language of the context is the same in each subject, making it easier for pupils who speak the home language as their second language to understand skills and concepts being covered.
- Mathematics becomes more understandable as it has a real context.

This is particularly important in a society where pupils access so much digital information which is not separated into convenient subjects.

Mathematics, language and ICT are natural partners with science and improve communication of science ideas. They are therefore central to a cross-disciplinary approach. There are also good possibilities to incorporate science investigations with other subjects such as history, geography and sport. The latter demonstrate that science is and has been important in society.

There are real gains to be made in developing the pupils' skills, knowledge and cognition in science and related subjects. However there is a risk that links are superficial. It is essential not to lose sight of the aim both to focus on developing inquiry methods and to improve pupils' learning. It is important to have clear learning objectives in each separate subject in activities developed. Consequently teachers need good and sustained in-service training to develop their pedagogical and conceptual skills in all subjects concerned. This takes time and needs the active support of the schools' leaders.

It is well worth the effort as two Leicester teachers explain:

'The Fibonacci project links lots of things together. As a teacher, it provides me with confidence, inspiring CPD and the chance to discuss science and numeracy teaching with teachers in different schools and across different age ranges.' Sarah Eames

'One of the main benefits of the Fibonacci method [in science] is the integrated use of ICT. It's a great tool for learning with the biggest impact being the use of data and analysis. This develops the children's critical thinking skills and gives them confidence to challenge and ask questions. The maths curriculum contains a lot of data handling and using this method means you can cover that though science investigation.' Matthew Law

Appendix: Clarifying 'Science Inquiry Across the Curriculum'

The educational literature suggests different strategies for linking two or more disciplines. These include:

- An *Interdisciplinary* approach *which* can be defined as work that integrates knowledge and modes of thinking from two or more disciplines in ways that would have not been possible through single disciplinary means. Such disciplines are integrated to solve a problem such as explain phenomena and/or raise new questions (Boix Mansilla et al., 2000).

- In contrast *Cross-disciplinarity* keeps the different disciplines separate without transfer of methodologies. Within a cross disciplinary relationship, disciplinary boundaries are crossed but no techniques or ideals are exchanged while interdisciplinary relationships blend the practices and assumptions of each discipline involved. The working group, who developed this booklet, considered that while we were using inquiry methods we were not really combining methodologies of different disciplines. Each was still clearly identifiable even when applied together to solve a problem.

- The working group members felt that *Cross-curricular* was closer to our intentions as educationalists, i.e. to make links between different school curriculum areas to support learning in each subject. We also felt that is important not to lose sight of our aim both to focus on *developing inquiry methods* and to improve pupils' learning, so it was important to have clear *learning* objectives in *each* separate subject in activities we developed.

Consequently the group considered that '*Integrating science inquiry across the curriculum*' best represented the conceptual and skills needs of each subject that schools are required to teach in their curriculum.

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- Children can appreciate the contexts of their learning and so are more able to apply learning to their lives and develop a wider interest in the world.
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