Research for Teachers

Students' views about science theory and practice

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Why do students' ideas about science matter?
This month we feature the work of another influential educational thinker - Rosalind Driver (1941-1997).

Rosalind Driver is widely acknowledged, by teachers and other educational practitioners in England and abroad, for her contribution to our understanding of how children's ideas about science influence their learning. She began with the perspective that children construct their own ideas about the behaviour of the natural world, as a result of their observations of things happening and the ways that people talk about them. Many children, therefore, think about the process of seeing as involving something going from the eye ('giving a look') rather than light being reflected from an object into the eye. This perspective is consistent with a constructivist view of learning.

Driver's early work was completed in the early 1970s, when Piagetian views were influential. Such views suggested that children find science learning difficult because it requires formal abstract reasoning. Driver, however, showed that children are capable of abstract reasoning in some contexts - while they found 'simpler' forms of reasoning extremely difficult in contexts that are counter-intuitive (after all, the world really does look flat...!). Driver pointed out that the interpretation of scientific phenomena by scientists occurs within a framework of ideas and beliefs held by the participants - and that children's ideas are also shaped by the experiences and ideas that they encounter in everyday life.

Driver argued that if children were to develop an understanding of the concepts of science as accepted by the scientific community, they needed to be offered more than just practical experiences. They needed teachers' guidance to help them develop new ways of thinking about their experiences. This often involved children making an intellectual leap by abandoning personal 'alternative frameworks' which, up until then, had worked well for them. During discussions designed to help children make this leap, teachers prompt them to make their thinking explicit, and support them in engaging with new ideas.

This Research for Teachers summary explores the key themes of the 2008 reprinted edition of Driver's 1983 work, 'The Pupil as Scientist?' We have selected this book as the focus of this summary because it documents and explores all her main ideas and findings. All page references in the summary refer to this work. In particular, the summary looks at Driver's propositions that:

- the alternative frameworks (the ideas that students have already formulated, sometimes described as alternative conceptions) that students bring with them to science lessons may be at odds with the theories the teacher may wish to develop;
- students' alternative frameworks affect their observations and the sense they make of them; and
- teachers can help their students develop the concepts and ideas of science agreed on and accepted by the scientific community.

Driver continued to develop and refine her work through a series of studies. For example, she increasingly acknowledged the importance of Vygotsky's ideas of learning in which children create their ideas in the social context of discussion with their peers. This and other developments were drawn together and summarised by her colleague John Leach in 'Rosalind Driver (1941-1997): A tribute to her contribution to research in science education'.
It's not just important, historically, that Driver's work helped change practice, but this Research for Teachers summary offers teachers access to some of the thinking behind current teaching and learning approaches in science. The findings from Driver's work and the ideas she proposed about children's thinking in science should help teachers of science at all levels reflect on their own practice and plan future teaching.

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Overview

Driver, R. (1983) *The pupil as scientist?* Open University Press.

Why is the issue important?
Rosalind Driver (1941-1997) challenged the traditional approach to teaching science that was underpinned by the idea that scientific knowledge derives from first-hand sensory experiences recorded through experiment and observation. She argued instead that the ideas children already held about science (alternative conceptions) were the key to how children created meanings about science for themselves. Driver's findings were first presented in her book The Pupil as Scientist? (1983, reprinted 2008), and have continued to inform science teaching and learning.

What are the key messages?
Driver believed students' used their alternative conceptions to help them understand their everyday experience of science, which had in the past served them well. However, they could hinder students' acceptance of more advanced scientifically accurate concepts. Specifically she provided evidence to show how students' alternative conceptions:

- may be at odds with the theories teachers were trying to develop; and
- can affect pupils' observations and the sense they make of them.

In order to guide students in developing new ways of interpreting their experiences of science, Driver believed teachers needed to pay more attention to the development of specific ideas and concepts than to generalised thinking skills.

How did Driver arrive at her ideas?

Over a span of almost 30 years Driver explored students' thinking about science and its implications for teaching and learning, particularly in a series of action research studies which led to The Pupil as Scientist? Driver continued to investigate children's ideas in science in the Children's Learning In Science Project (CLISP) (1982-1989) of which she was Director. Driver and her colleagues explored, observed and analysed students' reasoning about topics such as matter, heat, plant nutrition, energy, light and air, using diagnostic questions they had previously designed and piloted.

What are the implications?
Driver's work underscored the importance of teachers:

- helping students make their alternative conceptions explicit
- adopting strategies that relate teaching to what is familiar to children, not just at the level of experiences but also in their world of ideas
- identifying students' learning difficulties in science and supporting them in assimilating new ideas; and
- helping students understand the nature of the scientific method.

What do the case studies illustrate?
The case studies show the contemporary relevance and importance of Driver's findings and ideas. They show for example, how:

- a teacher explored the ways young children believed our senses worked to detect what is in our surroundings
- older post-16 students engaged in learning science through a combination of their own research and expert input; and
- secondary school teachers designed and used diagnostic probes to explore their students' existing thinking about scientific phenomena.

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Study

Can students make sense of scientific phenomena for themselves?

Although students enjoy experimenting in science and believe they can discover things for themselves, Driver's observations of students at work in the classroom and laboratory suggested that students' own discovery approaches were insufficient for developing their understanding of science phenomena. When students make and record observations they are influenced by a number of factors including:

- being unclear about what features to focus on, for example, when drawing living cells, or the patterns of iron filings around a bar magnet;
- holding preconceptions or expectations, for example, about the random movement of smoke particles in air; and
- being unfamiliar with the use of scientific conventions such as lines of force or rays of light.

Driver concluded that children do not know what aspects of a situation to pay attention to and what to ignore, for example, they painstakingly drew air bubbles trapped on the microscope slide rather than the features of the cells. When studying the random motion of smoke particles (Brownian motion) many 11-year-old pupils believed the smoke particles changed direction because they collided with each other, rather than because of bombardment of the smoke particles by unseen molecules of air. For example, one student commented:

'When smoke particles collide and move in different direction we call this random motion.'

Driver suggested that this is what they believed they saw because they expected to do so. When the teacher asked them to observe more closely to see if this was what actually happened, they realised this wasn't the case.

When 11-year-old students were asked to observe light passing into and coming out of a prism and then represent what they thought was happening, many of them showed the light rays as curves rather than straight lines. Similarly, children at first found it difficult to draw diagrams showing the patterns of iron filings around the ends of a bar magnet. In both cases children did not, and were not expected to, draw diagrams like their teachers' and those appearing in text books, until they had been trained in the appropriate scientific conventions.

You might like to read a case study that shows how young children represent their ideas about how our senses work.

Driver believed that students could not make sense of what was happening by themselves and needed teacher guidance to help them do so: 'On the one hand pupils are expected to explore a phenomenon for themselves, collect data and make inferences based on it; on the other, this process is intended to lead to the currently acceptable scientific law or principle.' For this reason she later had major reservations about approaches to science known as 'process science.' These emerged in the 1980s and 1990s, and focused heavily on experimentation. Driver and her colleagues also questioned whether some of the 'processes' were unique to science, and whether they were teachable at all (See Leach p 5, Further Reading).

You might like to read a case study describing how older students combined their own research and observation with expert input to extend their understanding of science concepts.

How do students' alternative conceptions influence their interpretation of scientific phenomena?

During several periods of research, Driver and other researchers explored children's thinking about scientific phenomena during their science lessons. They documented a number of common alternative conceptions which stemmed from children's everyday experiences and the expectations which grew from them. For example:

- In a lesson about electrostatics for 13-year-olds, the teacher inflated a balloon, rubbed it to charge it up and held it over some small bits of paper which then fluttered up and down. When they were asked to explain, a typical response from the pupils was: 'Please sir, is it that when you rub the balloon you let a little bit of air out and it blows the paper around?' (p 24)
- During a lesson on dynamics, 11-year-olds rolled marbles across surfaces. One group of pupils was asked to explain why a marble rolls then stops. One response from a pupil was: 'I don't know. Why do they stop?...After you push it they go as far as the push...how hard it was and after that wears off it just goes back like it used to be.' Here the student believes the movement depends on the initial impetus the pusher gives and that when it is used up it returns to normal rather than more scientific explanations, such as one involving the role of friction. (p 26)
- Another example featured an experiment about heat. A class of 12-year-olds watched an inflated balloon placed on a heated tin can get bigger as the tin was heated. Students explained this in a number of ways including: 'I think it will-erm - blow up and pop with the force of the heat', '...the heat's pushing the air so it blows the balloon up', '...the heat's coming and collecting in the can.' These statements reflect the idea of heat as a substance, rather than as a form of energy. (pp 28-29)

Driver argued that children use a range of intuitive ideas to make sense of their experiences: 'All the ideas discussed so far are attempts by pupils to understand new events by relating them to what they know already.' They are ideas they are prepared to 'try out for size'. Usually, they are transitory and quickly abandoned in the face of contrary evidence or alternative explanations'. Finding out what prior ideas students hold about scientific events is vital for developing students' understanding.

You might like to read a case study which describes how teachers in a primary school developed and used probes to explore their students' understanding of science.

How persistent were students' alternative frameworks?

Although Driver believed science lessons had an effect on students' existing ideas of science, she also cautioned: 'Some of these ideas, or alternative frameworks, are characteristic of the thinking of many children, and may persist despite instruction'. Historically this is common in learning science and therefore it is not surprising that students will hold on to their existing beliefs. What follows are examples Driver gave of students using these beliefs as crutches even though they have access to the tools to see them differently (scientific theory/observation):

- Although they had been taught about the effect of heat on the speed of molecules, and the distance they can move to as a result, many 13-year-old students could not apply the concept to provide an explanation for the action of heat on metal. In trying to explain why mercury rose in a thermometer when it got hot, they spoke about '...heat making the particles expand..., '...mercury rises up the thermometer to get away from the heat...' '...the mercury's mass becomes bigger...' rather than using the ideas they had learned.
- Another illustration of students relying on existing understandings rather than observation concerned photosynthesis and the part played by the atmosphere and the sun. Many older students continued to refer to plant growth in ways such as '...most of the food of a green plant is obtained from the soil'.
- When students experimented with centre of gravity of shapes, they realised that for symmetrical shapes the centre of the shape was also the centre of gravity. Only one student in the class recognised that it was the distribution of weight that mattered, and that was why changing the shape could lead to a different centre of gravity, although the overall weight remained the same. He balanced a strip of card on a fingertip, then bent up an end and rebalanced the strip at a different point. '...I am changing the moment, the weight's the same - just nearer to the balance point.' This change of conception required an imaginative leap.

Driver argued that students needed guidance to help them assimilate their practical experiences into what was possibly a new way of thinking about them. Tenaciously held 'alternative frameworks' are not new. As Driver pointed out, the history of science is studded with examples where scientists' beliefs influenced the direction of their enquiries. For example, Count Rumsford (Anglo-American, scientist, 1753-1814) went to extraordinary lengths to establish whether objects got heavier when heated.

How can teachers change students' alternative conceptions?

Driver concluded that even when students appear to have understood an idea or principle they revert to alternative frameworks for their intuitions when faced with novel tasks. Making sense of what they had seen in the scientifically acceptable sense involved the intellectual leap of abandoning an alternative framework which, up until that time, had worked well for them. She suggested a number of ways teachers could help students advance their conceptual thinking in science, which we discuss briefly below.

Time for reflection

Driver proposed that students needed time to reflect on what they found: 'Where activities are intended to illustrate some concept or principle, then time is required for pupils to consider their results and generalise their findings to new situations'.

Making alternative conceptions explicit and building on them

She recognised that '...instead of ignoring the alternative frameworks that children have developed, science teaching programmes could benefit by taking greater account of them.' Driver believed: 'By making their theories more explicit in the formal learning situation children are able to explore their implications and make comparisons between one 'framework' or 'theory' and another'. Telling the students what is 'right' often meant the students simply put the new knowledge into their incorrect framework leading to lack of understanding later.

Driver increasingly recognised the need for students to talk together to share and compare ideas: 'Activity by itself is not enough. It is the sense that is made of it that matters. Teaching strategies are needed which help students think and talk about the significance of their experiences, and most important, time for teachers to talk through students' experiences with them.'

You might like to read a case study which explored students' use of dialogue to enhance their communication of their ideas about science.

Intellectual demands on students

Driver pointed out: 'It is important to recognise that in science lessons students are involved in learning at two levels at once: they are exposed both to new phenomena and also their accepted theoretical interpretation'. One example is the particle theory of matter which explains the observable behaviour of substances in terms of invisible particles. Another is the behaviour of electric currents where students observe concrete effects such as bulbs lighting up, motors turning, and buzzers ringing, whilst the explanation requires them to use the abstract concept of an electric current. Consequently she proposed that: 'For students who have difficulty in understanding the theoretical ideas in science perhaps it is necessary to reconsider the level of theory presented'.

Our Research for Teachers summary 'Learning Science' describes how teachers in the Evidence-based Practice in Science Education (EPSE) Research Network used diagnostic probes to investigate the learning demands that different science topics made of students. These teachers used the information to create lesson plans which built more naturally on students' ideas.

How can teachers help students understand the scientific method?
Driver recognised the tension between children carrying out scientific experiments to find things out for themselves, and the accepted concepts that science teachers were trying to get across to them. Nonetheless, she believed that learning the nature of science was part of learning about science. Three activities key to understanding how science works are discussed briefly below.

Experimenting for themselves
Driver believed that children had to experience scientific phenomena for themselves, using the methods of science: '...there is a case for including opportunities for pupils to undertake their own investigations, not in order to establish an important principle, but to gain some experience in planning an experiment using their own initiative.'

You might like to read a case study which features primary children engaging with the nature of science through investigation.

Comparing different conceptions
In Driver's view, the classroom or laboratory provided an arena in which teachers could surface examples of competing systems of belief or understanding that were held by students. This idea chimes with current views about the way science advances as well as providing learning opportunities. Thinkers about science have proposed that science proceeds '...not by an inductive approach of making generalizations [sic] about data, but that progress is made when an accepted theory competes with a new theory for the interpretation of data'.

Using models to explain scientific phenomena
In Driver's studies many students between the ages of 9 and 16 years did not recognise that observable features of phenomena (such as heat making a balloon expand), and theoretical entities used to explain phenomena (such as the simple model of molecules in constant motion which increased their speed and range when heated), were different kinds of knowledge which often led them to confuse observation with explanation.

You might like to read a case study which illustrates an ICT-based approach to supporting students in their understanding of scientific models.

What view did Driver have about science and about how students' learned?
Driver found the prevailing approach to science teaching, which was based on induction, or the idea that scientific knowledge emerges from our sensory experiences, as unsatisfactory for a number of reasons, some already mentioned. Her main contention though, was that students brought their own reasoning grown from their everyday experiences of science, to their study of science.

The idea that students hold preconceptions about phenomena that are resistant to teaching was not new at the time Driver began the research for her PhD thesis. However, Piaget's views about the importance of abstract reasoning were widely held among education practitioners.

Driver quoted the views of the educational researcher Ausebel who agreed with Piaget that each individual organises and structures their own knowledge. However, Piaget's model focused on students learning logical reasoning processes that were independent of the learning content. By contrast Ausebel emphasised that meaningful learning linked new knowledge to what the student knew and understood already: '...the most important single factor influencing learning is what the learner already knows. Ascertain that and teach him

[sic] accordingly'. You can read more about Ausebel and his ideas in the Further Reading section of this summary.

Driver's work reflected the influences of both Piaget and Ausebel. She suggested two ways of interpreting scientific phenomena:

- 'causality', which is when predictions/explanations are based on the individual's conceptual scheme, that is, arguments built on previous experience; and
- 'legality' which is when knowledge is acquired using logical thinking based more on form than content.

She suggested that although the two are linked, students tend initially to rely on causal thought, often based on misconceptions or alternative frameworks. Driver illustrated this point by referring to some examples she had observed. In one case, an 11-year-old investigated the factors affecting the time it took for a pendulum to swing when released from an elevated position. She changed the mass of the bob, the length of string and the angle from which she released the bob. The teacher asked her what made the bob swing fastest. Rather than refer to her results and reason from them, the student said giving it a 'hard push' at the start was the way to do it. She was basing her explanation on her previous experience of what it is like to hit a ball, rather than on the measurements she had made. Her expectation, based on previous experience, influenced her response to the teacher.

Driver argued that formal thought involving forming hypotheses, controlling variables and using relationships such as proportionality, provides a way of manipulating ideas. However, she suggested further that what students learn and understand from their experiences depends not only on the manipulation of ideas, but on the nature of the ideas themselves, i.e. on the conceptual schemes the pupil brings to the experience.

How did Driver arrive at her ideas?

Over a span of almost 30 years, Driver's research explored students' thinking about science phenomena and its implications for teaching and learning in science. This research includes the series of action research studies which led to her first book 'The Pupil as Scientist?' (1983, reprinted 2008), on which we have based this summary. Driver's investigation and characterisation of children's ideas in science continued in a number of other studies (See Leach, Further Reading) in the Children's Learning In Science Project (CLISP) (1982-1989) of which Driver was Director. CLISP had a major impact on the development of the national curriculum for science in England, particularly in relation to the nature of science.

Driver and her colleagues observed and analysed students' reasoning about topics such as matter, heat, plant nutrition, energy, light and air, and involved:

- designing and piloting diagnostic questions which probed the knowledge students used in their efforts to explain natural phenomena, rather than their knowledge about specific scientific concepts; and
- characterising students' thinking about science in their own terms, rather than in those of accepted scientific theories.

What are the implications for your practice?

Teachers may like to consider the following implications relating to teachers understanding how students think about science, a key area of activity whose importance we can't stress enough:

- Driver's research highlighted the importance of teachers knowing what the students already know and understand in order to identify suitable starting points for learning. Would you find it helpful to spend time exploring what your students understand about a topic, and how they have already experienced the content, before you start it?

  You could perhaps present them with common misconceptions (see for example our Research for Teachers summary 'Learning Science' to find some examples) and see which ones they agree or disagree with.

  Alternatively, you could work with colleagues to draw up and share a list of misconceptions based on their experiences of students' learning, or you could design your own probes (see case study 3, or look at the 'Learning Science' summary).

- Offering students the opportunity to talk through their ideas together was seen as an important way of making students' alternative frameworks explicit. For example, could you build an element of collaborative discussion into some of your lessons by specifically planning time after an experiment for students to produce a conclusion together?

- Driver concluded that giving students the chance to conduct their own investigation was important for introducing them to the scientific method. Could you build into your lesson planning a number of more open-ended activities in which your students were able to take more ownership after appropriate prior discussion of the scientific method, and as far as health and safety considerations allow?

School leaders might like to consider the following implications:

- Driver's work suggested that getting the balance between letting students find out for themselves, and at the same time assimilating the key ideas of science was difficult. Could you offer time to science colleagues to engage in collaborative planning of the teaching and learning of the nature of science?
- One idea to emerge from Driver's research is that students would benefit from carrying out their own investigative work. Do you have colleagues who have particular skills in designing open-ended tasks that lend themselves to investigation? Could you arrange time for them to coach others in designing and implementing such activities? Or would it be possible to offer teachers time to work together to plan and build these skills?
- Driver suggested that offering students time to discuss their ideas helped to make their misconceptions explicit, and provided opportunities for teachers to build on the students' thinking. Would it be helpful to make this approach a feature of CPD aimed at enhancing learning across a range of subjects?

Gaps in the research

Gaps that are uncovered in a piece of research have a useful role in making sure that future research builds cumulatively on what is known. But research also needs to inform practice, so practitioners' interpretation of the gaps and follow-up questions are crucial. We think the following kinds of studies would usefully supplement the findings presented in this summary:

- more enquiry or research into how to diagnose or identify students' existing conceptions in science and build on them particularly in relation to, for example, the nature and behaviour of electric currents in simple circuits, the relationship between forces and motion, the particle model of matter, and photosynthesis in plants;
- more studies, particularly longitudinal ones, of the impact of different approaches to children's learning of science; and
- more research into science teaching and learning practices in England, particularly those which address children's adoption and use of models for explaining scientific phenomena.

What is your experience?

Do you have any evidence regarding strategies for developing the curriculum in ways that are particularly effective in meeting the needs of your pupils? Do you have action research or enquiry based school strategies/experiences or programmes that are designed to explore new ways of presenting the curriculum? We would be interested to hear about examples of effective approaches that could perhaps feature in our case study section.

Your feedback

Have you found this study to be useful? Have you used any aspect of this research in your own classroom teaching practice? We would like to hear your feedback on this study. Click on the feedback link 'Tell us what you think' to share your views with us.

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Case Studies

We have chosen six case studies to complement and illustrate aspects of the findings reported in this summary. Together they show the continuing relevance and applicability of Driver's ideas in current teaching and learning of science. The case studies show how:

- a teacher explored the ways young children believed our senses work to detect what is in our surroundings;
- students engaged in learning science through a combination of their own research and expert input;
- secondary school teachers designed and used diagnostic probes to explore their students' existing thinking about scientific phenomena;

- teachers improved students' understanding of science through collaboration and dialogue;
- ICT helped Year 10 and 11 students gain a better understanding of chemistry topics which are hard to teach, such as particles and their behaviour; and
- teachers guided primary school pupils in exploring and understanding the nature of the scientific method, including designing and conducting their own investigation.

Case study 1: Do children have similar models of understanding for seeing, hearing and smelling?

We selected this case study because it presented an illustration of the ways young children believed our senses worked to detect what's in our surroundings. The pupils involved in the study were Year 3-6 boys and girls (7-11 year olds) from one school in the English West Midlands. The study was based on the responses of 335 primary school pupils, of whom 85 were in Year 3, 84 in Year 4, 88 in Year 5 and 78 in Year 6. The children came from different cultural backgrounds including Indian, European, West Indian and Pakistani.

The study aimed to find out:

- what kinds of models children bring to their learning about the senses and how this knowledge can inform teaching strategies; and
- whether children have similar models of understanding for seeing, hearing and smelling.

While the students in this school were taught about hearing and smelling in Year 5, and seeing in Year 6, this study was carried out at the beginning of the academic year before the students met the topics in question.

How was the study carried out?
The teacher-researcher used drawings to explore the children's ideas about the work of the senses. Each child was given pencils, erasers and three sheets depicting a clip-art scenario for each of seeing, hearing and smelling. They were asked to 'use lines, arrows and words to show how you see, hear and smell'. A sample of 30 children were then interviewed in order to complement the analysis of the drawings. This study used an analysis of the drawings, the children's use of lines and arrows, and their annotations to find out how they thought the senses worked.

What the study found
The students used five common models across all year groups for seeing, hearing and smelling. These were:

- the receptor: nose, eyes, mouth, etc. (this is the scientifically accepted model);
- outreaching: an active seeking out of stimuli;
- sensing as instant: a belief that stimuli and events interact simultaneously;
- clashing arrows: a meeting of outreaching and stimuli somewhere outside the body; and
- arrows both ways; a dynamic interaction between stimuli and receptor.

The outreaching and sensing-as-instant models were the most frequently used model. Least common were the receptor and clashing arrows models. It was also found that:

- children's models were context driven, in that they often had totally different models for each of their senses;
- very few children who used the receptor model for one sense used it for all three; and
- the outreaching and sensing as instant models were held very persistently.

Samples of the children's diagrams are presented in the summary of the research published by the National Teacher Research Panel.

The study's conclusions
The findings suggested that these pupils were carrying alternative conceptions that could conflict with the conventionally accepted ideas they will meet later. Teachers needed to revise the approach they currently used in order to challenge children's beliefs about scientific phenomena, and make them more receptive to the scientifically acceptable conceptions.

Reference

Cuthbert, P. (2006)
Do children have similar models of understanding for seeing, hearing and smelling?

Case study 2: Stretching sixth-form scientists

This case study was selected because it showed how students engaged in their own research, complemented by expert input, helped them develop their scientific understanding further. The school involved in the study was a mixed 11 to 18 comprehensive with a record of satisfactory A level results in the sciences. Few students gained top grades, and gifted students were often less successful in sciences than in their other subjects. The teachers felt there was a need to raise interest and motivation in the sciences by increasing the range of extension and enrichment activities on offer to sixth-form science students.

What kinds of activities were students involved in?

The A level subject specialists used their subject knowledge to share ideas and, as a result, offered all A level students two key opportunities:

- researching, preparing and delivering a presentation; and
- conducting an experiment of their own choice.

For their presentation activity the teachers asked the students to choose a topic that really interested them and to carry out research that met, and where possible went beyond, the requirements of the subject specification. Students were encouraged to work individually but could work in pairs if they felt it necessary.

Topics chosen by the students included:

- investigating sources and effects of the components of acid rain;
- using entropy and free energy values to predict and explain reactions;
- researching and explaining the use of radioactive dating methods;
- researching the history of synthesis of well-known drugs and medicines;
- carrying out an in-depth study of some common enzymes and their effects;
- investigating the variation of breathing rates and the composition of inhaled and exhaled gases with exercise, using a wide sample of people;
- investigating the science behind the fuels of the future;
- summarising the life cycle of the stars;
- studying the Earth's magnetism in the atmosphere; and
- explaining common misconceptions or fallacies in science.

Each presentation was followed by a question and answer session which gave the students the opportunity to contribute further evidence.

The second extension activity involved students in carrying out their own experimental work. They could choose either a new experiment that they had devised themselves, or a repeat of a well-known experiment. The aims of the activity were to:

- encourage students to think of themselves as 'real scientists' when planning and carrying out experimental work;
- stress the value of practical skills; and
- improve students' practical techniques.

How was students' learning encouraged and supported?

The school offered students a number of other activities to enrich and support their learning including:

- visiting the local university's science labs to try some of the advanced equipment that they would use on a university science course;

- attending open lectures organised by the Royal Institution and local Association for Science Education (ASE) groups;
- visiting a local observatory to use the telescope; and
- setting up a senior science club.

The science department also asked two local university tutors to contribute by visiting the school and sharing ideas.

What effect did the activities have on students' learning?
The school's extension activities for advanced scientists were linked to a number of impacts including:

- more A and B grades at AS and A level;
- better interviews at university and in industry;
- greater enjoyment, interest and expertise in science;
- more independent learning and innovative thinking as a result of their research and presentations;
- lifelong learning habits in planning, handling information, carrying out individual research and using ICT to find new information;
- better skills in communication, application of number and problem solving, with science evidence contributing to level 3 key skills qualifications; and
- students' greater confidence and skills in practical work.

There was evidence that students took up these challenges with growing enthusiasm. The study also reported increases in the students' skills, particularly with reference to:

- reading widely around a subject;
- calling on facts to back up ideas;
- recognise patterns; and
- predicting the possible outcomes of experiments.

What next?
The school planned to introduce group debates (in teams of three) on scientific issues such as pollution, cloning and radiation, perhaps judged by local university staff. The leading teams will then be offered the chance to enter the BA Science Communicators' Award competition.

Reference
Qualifications and Curriculum and Development Agency. (2010) Stretching sixth-form scientists. *QCDA: Guidance on teaching the gifted and talented.*

Case study 3: The use of diagnostic probes

We chose this case study because it showed how secondary school teachers designed and used diagnostic probes to explore their students' existing thinking about a number of scientific phenomena. The study involved 200 students in 10 classes at the school which was situated in West Yorkshire. The pupils were mainly from Years 7, 8 and 9.

The aim of the study was to uncover students' existing ideas about natural phenomena which they will study. Specifically, the teacher-researchers planned to:

- investigate how diagnostic probes might be used to uncover these existing ideas;
- identify the role which diagnostic probes could have in the teaching and learning of science; and
- find out if they were effective in identifying students' alternative conceptions.

How did the teachers devise and develop the diagnostic probes?
The teachers acknowledged that they could identify students' understanding of scientific concepts through a range of existing methods such as, interviews, concept maps, students' writing, games, conflict situations and pencil and paper tests. However, they believed these approaches were time-consuming and they wanted an approach which would identify students' levels of understanding within an area of science, yet remain an

unobtrusive part of teaching. The teachers reviewed research on children's understanding in science, particularly the categories of ideas which pupils have, and used it as the basis for developing the probes.

In each of the areas chosen, the teachers devised probes and trialed them with a small group of students. The results of these tests were then analysed and compared to the findings of previous research. The categories uncovered by the probes enabled the teachers to further refine the probes prior to use with the main test groups of students. This case study focuses on the topic of inheritance.

What did research say about children's conceptions of inheritance?
The review of research revealed that the following ideas were held by students.

- Some features are inherited from parents.
- Humans are more unique than similar, i.e. we are all different from our parents and each other.
- Boys inherit more things from their fathers than girls and vice versa.
- Different organisms inherit features to different degrees. Humans inherit many of their features, then mammals, then other animals, but plants inherit only to a small extent.
- Acquired characteristics are inherited particularly if the feature has been present for a long time in the parent or it has been present over several generations.

Note for non-scientist readers from the Research for Teachers team:

There are several misconceptions here. All living organisms inherit features from the parents to similar degrees. Whilst each individual member of a species is unique, there are many more similarities than differences between members of the same species, but it is not surprising children focus on the differences. There are a small number of inherited characteristics that are linked to the gender of the adult, for example, the tortoise-shell coats of some cats are almost entirely found in females, and haemophilia in humans is much more common in males than females. Common characteristics present in humans, such as eye colour, hair colour, tongue rolling, etc. can come from either parent. Acquired characteristics can appear to be inherited if they occur in the same family over many generations, perhaps an occupation that seems to be 'passed down', or an interest in something, but acquired characteristics are perpetuated through a constant similar environmental pressure or condition rather than through a genetic inheritance mechanism. Overall the research suggests that children have poorly formed ideas about the purpose of sexual reproduction.

How did the teachers explore students' views about inheritance and what did they find out?
The teachers created three probes to explore this area of science.

- Features - In this probe the pupils were asked to sort pictures of inherited and acquired characteristics in humans, mammals, invertebrates and flowering plants, into those they believed would be inherited and those that would not. This showed the extent to which the nature of the organism influences children's beliefs about inheritance.
- People - Students predicted the likely appearance of the son and daughter of a couple whose features differed in three ways. This explored whether students thought inheritance was gender-linked in humans.
- Puppies - Students were given a picture of a dog and were asked to predict which three features could be passed onto its puppies. Two of its features were labeled as having been acquired since birth. This showed the sorts of features students thought could be passed from parents to offspring.

Teachers found that their students' beliefs and ideas were consistent with previous research reported in the literature. Students largely agreed about which features would or would not be inherited by humans. There was less agreement about inheritance in plants and invertebrates. Most students believed that features such as height and hair colour are sex-linked, i.e. parents pass features onto a child of the same sex. Students tended to believe that features influence genes as well as vice versa. The earlier a feature was acquired in the life of an animal, the greater its chance of being passed on to the next generation.

What did the teachers suggest probes can be used for?
The teachers initially regarded diagnostic probes as a means of providing teachers with the ideas that students have as a starting point for teaching and learning. But as the study progressed, they realised that the probes could be used for a number of purposes including:

- measuring students' existing understanding prior to teaching a topic;
- as a learning activity to challenge and stimulate students' thinking;
- to assist teachers in reviewing and developing schemes of work; and
- enabling teachers to set targets for individuals and groups of pupils.

Reference

Nixon, D., Kirk, H. & Needham, R. (1998)
The use of 'diagnostic probes' to aid teaching and learning in science

Case study 4: The 'Thinking Frames' approach

The 'Thinking Frames' approach: enhancing students' understanding of science through collaboration and dialogue

This case study was chosen because it illustrated how teachers improved students' understanding of science through collaboration and dialogue. The study was carried out in a number of schools by the Cams Hill Science Consortium which involves over 30 teachers from 27 different primary and secondary schools across Hampshire, East and West Sussex. The group has engaged in a variety of action research programmes in teaching and learning science across Key Stages 1, 2, 3, 4 and post-16. This case study was based on work in science at Key Stage 3.

How did teachers and students use the strategy?

The teachers used a strategy known as 'Thinking Frames' which had been designed by the consortium. The strategy was implemented in a number of stages described briefly below.

Discussion

Teachers engaged students in discussion about the science activity they were undertaking. This involved teachers helping students to visualise the thinking skills a learner needs in order to apply scientific models and modeling, so they can then form their own explanations as they progress through the school science curriculum. Teachers produced placemats which summarised the models, descriptions and vocabulary that their students should be familiar with.

Teachers enlarged the placemats into wall displays, or used them on interactive whiteboards via PowerPoint presentations to create Key Models sheets. The activity involved students in selecting appropriate models to explain the scientific phenomena they were studying. During the activity the students discussed together and compared and adapted their explanations. Students added their own views to the wall charts using felt-tip pens.

Teachers encouraged students to work together to write down all of the scientific vocabulary and ideas that they thought would be relevant to answering the question posed by the investigation they were tackling. They used the Key Models sheets to help them share ideas and prioritise the most important ideas and vocabulary.

Producing visual models

Students created their own models and explanations for what happened in the experiments and wrote them down on prepared Thinking Frames sheets. Students drew pictures and diagrams to help them to explain the processes they observed. For example, after being shown a sunflower seed and a fully grown sunflower, students were asked: "How did the sunflower get heavier?" In the 'See' box of their worksheet they were encouraged to draw stages in the growth process. Teachers explained that there were not necessarily right or wrong answers, but that the process of drawing helped them to think. Teachers went round the groups assessing progress by talking with the students, encouraging them to discuss their drawings and annotations, and identifying learning difficulties.

Thinking and sequencing
In this part of the activity students were asked to write down up to five bullet point statements that explained what was happening in their 'See' section. Teachers resisted the temptation to correct the students if they got an incorrect sequence, as students needed to experience the difficulties for themselves.

Paragraph section
Teachers asked students to complete this activity to help them improve their skills in writing explanations about abstract scientific phenomena and processes.

What did the study find out?
Members of the Consortium provided a portfolio of evidence including data lesson observations, sampling of pupils' work and interviews with students and teachers. Evidence indicated that students benefited by acquiring a sense of direction and purpose in their science work. As the comments from students below show, they improved their science vocabulary and developed increasing sophistication in their explanations. Although the comments were contextualised with reference to national curriculum attainment levels, they show students' acquisition of more complex understandings:

'That's ok because we have got the scientific words needed for a level 4 answer - what explaining have we got to do to get a level 5?.

'No that can't be level 6 because he hasn't explained the particles in enough detail.'

Below is an example of work produced by a Year 7 previously underachieving student with very low literacy skills, and a previously low self-esteem.

Katie's Thinking Frame problem solving paragraph
Why are we able to separate salt from the sand?
'The particles separate when one solute dissolves. The salt dissolves. The sand doesn't. The solvent gives the salt particles energy to help the salt dissolve. The sand does not dissolve. The water mixed with the salt went through the filter paper sand was left behind.'

Reference
NTRP. (2006)
'Thinking Frames' approach to improve pupil engagement and attainment in science.

Contact the authors and the Cams Hill Science Consortium

Case study 5: Using SMART Notebook to understand chemical reactions

This case study was selected because it showed how ICT could help Year 10 and 11 students gain a better understanding of hard-to-teach chemistry topics such as particles and their behaviour. To fully understand topics like these students need to use abstract models, which are usually presented to them, but which challenge them to make a leap in their understanding. Whilst Driver did not refer to the use of ICT, teachers have found it useful because it enables students to explore dynamic situations which are otherwise difficult to represent.

The aim of this case study was to help students understand the term 'effective collision' between particles. This is a key concept in chemistry and refers to a model in which particles of matter such as atoms, molecules, etc. interact to create a chemical reaction. However, students find the ideas difficult to grasp because particles are difficult to visualise, particularly their dynamic aspects. The case study was the result of a joint effort between Becta and the Association for Science Education (ASE), and was carried out at a specialist technology college. The proportion of students with English as an additional language was above average.

What are SMART Notebooks and how were they used to support learning?
The science teachers used SMART Notebooks to cover topics in Key Stages 3 and 4 (Notebook is SMART's whiteboard software. It acts as an electronic notebook and can be used to save notes and drawings written on an interactive whiteboard, or downloaded at a desktop computer. Graphics, text and multimedia formats can be imported into the notebook's file or exported from the file to HTML, PDF or PowerPoint.)

The Notebooks were uploaded to the school's learning platform so that:

- students could access resources from outside school; and
- the resources could be shared among staff via the school's intranet.

Students accessed the resources in science lessons using a whiteboard, in ICT suites or on a computer with an internet link via the school's learning platform.

How did students use the Notebooks to study the particle model?
The study reported how teachers and students used the Notebook to provide the illustrations they used to interpret how and why a chemical reaction happens. Specific aspects of chemistry covered in the topic included how:

- matter is composed of particles;
- particles behave differently as heat is applied; and
- particles interact with each other.

The students studied web-based animations that highlighted key features of chemical reactions, using models from various sources, including:

- Freezeray.com;
- Multimedia Science School 11-16 v2.0;
- OUP Twenty First Century Science flash animation; and
- the RSC Alchemy resource.

The animations helped students to visualise particle interaction during chemical reactions. They also allowed students to manipulate the particle model to predict and investigate the effects of changing variablessuch as concentration, surface area and temperature on the rates of chemical reactions. Students were able to replay animations and control variables at their own pace.

How did students benefit from using the resource?
Students pointed out the usefulness and accessiblity of the resource:

'It can be used outside the classroom.'

'I can check understanding at home if I need to.'

The students' coursework showed an improved understanding of particle behaviour, as reflected in teacher observations and these comments from students:

'I have proved my prediction to be correct; as the concentration of the acid is stronger the reaction happens faster. The stronger the acid is the more acid particles there are, this means there are more effective

collisions between the particles, creating a faster reaction.'

'An increase in temperature affects the rate of reaction. The warmer the acid the more kinetic energy the molecules have. This makes them collide with the thiosulphate molecules at a greater speed, there are more effective collisions and the overall reaction is quicker.'

Reference
Mason, C. (2009)
Using SMART Notebook to understand chemical reactions
Salendine Nook High School Technology College, New Hey Road, Salendine Nook, Huddersfield, W. Yorkshire, HD3 4GN

Case study 6: The greenhouse construction activity

We selected this case study because it showed how teachers guided primary school pupils in exploring and understanding the nature of the scientific method, including designing and conducting their own investigation. The teachers ran the activities as a competition for all primary Year 5 classes (pupils aged 10-11 years old) with three to four pupils in each work group.

What the activities consisted of
The project was based on three activities which are described briefly below.

Activity 1
The teachers guided pupils in carrying out a close-ended investigation of the effect of the rate of evaporation on temperature. After the experiments, teachers explained the concepts of making hypotheses, defining variables, testing hypotheses, analysing data and making conclusions. The activity also offered the pupils the opportunity to rehearse their practical skills, including setting up an experiment and reading instruments.

Activity 2
This activity was designed to reinforce the ideas about the scientific method the pupils had been introduced to in the previous lesson. The pupils were given a short story about a scientific event and were asked to identify the parts of the story which referred to the various stages of the scientific method.

Activity 3
This activity aimed to give the pupils the opportunity to test out their existing investigation skills rather than for the teachers to teach them those skills. Firstly, teachers demonstrated the way a greenhouse worked. The experiment consisted of a thermometer placed in three locations outside in a sunny location:

- in the open;
- inside a closed paper box; and
- inside a closed paper box with a transparent 'roof".

The groups were then asked to construct their own small greenhouse with a container holding 10cm? of water inside. The pupils' performance was assessed by the size of the temperature rise in the water over a period of 20 minutes. The teachers encouraged them to change at least one variable, such as the size, the number of transparent sides, the colours of the greenhouse and the container, etc. During the practical work, teachers walked among the groups asking questions and assessing their work. After the activity each group presented and explained their designs to the teachers and other pupils and suggested possible improvements they could make. The pupils were invited to study and grade other groups' designs according to:

- effectiveness;
- environmental friendliness; and
- creativity.

Prizes were awarded for each category.

How did students benefit from the activities?
Teachers reported that most of the pupils were highly motivated, including slower learners, and worked well collaboratively. They noted that the occasional small 'conflicts' were constructive and showed pupils presenting their own and engaging with each other's ideas.

Pupils engaged in active learning using an encyclopedia and borrowed books from a 'Science Corner' set up as a result of collaboration between the school's and local libraries.

Teachers reported that pupils were able to link the various elements of the case study in Activity 2 to the common practices of science.

Reference
Fan, K. (2005)
Solar energy investigation activities for primary pupils
Asia-Pacific Forum on Science Learning and Teaching, 6(1)(7)

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Further reading

Bibliographic references

Rosalind Driver's books:

Driver, R. (2008)The Pupil as Scientist? Open University Press: Maidenhead UK.

Leach, J. (1998)
Rosalind Driver (1941-1997): A tribute to her contribution to research in science education
France: Science Education Summer School

Ausubel, D. (1968) Educational psychology: a cognitive view. New York: Holt, Rinehart and Winston Inc.

Related research

DCSF. (2004)
Untangling dimensions of middle school students' beliefs about scientific knowledge and science learning

DCSF. (2004)
Changing students' scientific misconceptions

DCSF. (2004)
The effects of an integrated, activity-based science curriculum on student achievement, science process skills, and science attitudes

Outputs from the Teaching and Learning Research Programme (TLRP) Evidence-based Practice in Science Education (EPSE) project, in the form of briefings, conference papers and some research papers from the network
TLRP and EPSE outputs

Resources

The following websites support science learning in different ways.

Alchemy
This resource provides 15 topics each of which concentrates on a single process from the chemical industry, supported by a video clip.

Freeze Ray: Teaching aids for use with interactive whiteboards
This website provides simulations for science topics that are hard to teach.

Science Buddies: Experimenting with the scientific method
This resource is aimed at supporting inquiry learning.

Teaching Ideas: Science teaching ideas
This website features many ideas for challenging primary age learner.

Twenty First Century Science: Useful websites
This link provides access to a number of other websites which support science teaching and learning.

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Appraisal

Driver, R. (1983) *The pupil as scientist?* Open University Press.

Robustness
Driver and her colleagues explored, observed and analysed students' reasoning about topics such as matter, heat, plant nutrition, energy, light and air through a series of action research studies. To do so they designed, piloted and then used diagnostic questions to explore children's thinking about these key topics.

Relevance
Driver's findings led her to challenge the current approach of the time to teaching science which was based on the premise that scientific knowledge flows solely from first-hand experiment and observation. Just as practising scientists already held concepts in their heads when they set about their research, Driver argued that the ideas children already held about science (alternative frameworks) were the key to how they created meanings about science for themselves. Driver's research contains key messages for science teachers and policy-makers who are interested in developing science teaching and learning so that it builds on and extends their students' experiences of, and their ideas about science.

Specifically Driver explored a number of issues of central importance in science education including, how:

- students' alternative conceptions (their already formulated ideas) may be at odds with the theories the teacher may wish to develop

- students' alternative conceptions affect pupils' observations and what they make of them; and
- teachers need to structure their students' learning of science on the basis of specific ideas and concepts rather than generalised thinking skills.

Applicability

Science teachers at all levels will find Driver's research helpful when reflecting on their own practice, and planning future teaching, specifically in relation to:

- helping students make their alternative conceptions explicit through shared reflection and collaboration
- adopting strategies that relate teaching to what is familiar to children, not just in terms of their experiences but also of the ideas they currently hold
- identifying students' learning difficulties in science and supporting them in assimilating new ideas by constructing appropriate schemes of work, and
  helping students experience and understand the nature of the scientific method.

Writing

The Pupil as Scientist? deals with complex issues such as the nature and philosophy of science, and the psychology of children's thinking in a highly readable way. The material comprising this book is well-structured in chapters with appropriately-descriptive headings and sub-headings, and the text is interspersed with key quotations from other thinkers. Frequent illustrations of students' thinking and actions while engaged in science activities, help to make the text both interesting and lively as well as setting the students' behaviour in contexts familiar to most science teachers.

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