Research for Teachers

Learning science

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How can teachers develop children's ideas about science?
Raising students' achievement in science has been, and remains, one of the pre-occupations of educational systems the world over. In the UK, for example, the science curriculum has undergone a series of structural changes dating from the late 1980s to the present time. However, many science education practitioners would argue that whilst the structure and to some extent the content have undergone change during this period, far less attention has been paid to teaching and learning processes in science classrooms and laboratories. Others, too, would suggest that there are important questions about what we teach and why we teach it that need to be addressed.

The 'Evidence-based Practice in Science Education (EPSE) Research Network', part of the Teaching and Learning Research Programme, has attempted to explore ways in which research on science education might make an impact on practice and policy. Researchers and teachers worked together to produce tools that helped teachers tackle problems relating to science teaching and learning in their classrooms. Specifically they focused on students' learning difficulties with some core science topics and on students' understanding of the nature of scientific knowledge, the procedures of scientific enquiry and the forms of reasoning used by scientists in interpreting evidence and proposing conclusions. The research is underpinned by the principle that students and teachers can work together to create meaning from scientific evidence.

The researchers highlighted differences between the language students use to describe and explain scientific phenomena in their everyday lives and the more scientific language needed for a clearer understanding of science concepts and ideas. They also stressed the core role of the teacher in presenting the content in a way which addresses known learning difficulties for students and in creating and sustaining the open-ended classroom dialogue which prompts students to reflect more deeply on their understanding.

We think that science teachers will find our summary of the work of the EPSE team helpful in reflecting on how they can build on their students' talk about science when planning approaches to teaching.

This collaborative research involved the Universities of York, Leeds, Southampton and King's College London and a number of science teachers and their classes.

The EPSE Network carried out the following four projects:

- Using diagnostic assessment to enhance learning (led by Robin Millar, University of York)
- Developing and evaluating evidence-informed teaching sequences (led by John Leach, University of Leeds)
- Teaching pupils 'Ideas-about-science' (led by Jonathan Osborne, King's College, London)
- Users' perceptions of research (led by Mary Ratcliffe, University of Southampton)

The common thread which links the projects is the idea that research into science teaching can inform practice and that research outcomes are most effective when they are translated into tools and resources teachers can put to use in their classrooms. There are also messages for policy-makers involved in curriculum review.

In addition to summarising the work of the EPSE network, this TLA research contains web links to five case studies which were undertaken by other practitioners independently of the EPSE research.

You may also be interested in reading a related summary on Rosalind Driver's (1983) work 'The Pupil as Scientist?', which explores how children's ideas about science influence their learning.

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Overview

Why is the issue important?
Raising students' achievement in science is a key challenge for educational systems the world over. In England the science curriculum has undergone a number of changes since the late 1980s. But many science education practitioners believe the main focus of the changes has been the structure of the science curriculum and to some extent it's content, at the expense of teaching and learning processes in science classrooms and laboratories. Others, too, raise questions about what we teach and why we teach it; questions that are being tackled in the development of new issues-based science curricula, such as Twenty First Century Science, and in the ongoing debate among the Qualifications and Assessment Authority, government and science subject associations.

What did the research show?
Teaching strategies which recognised and built on students' everyday science knowledge and understanding helped them become more scientific in their thinking and improved their learning. Other students made learning gains even when the new strategies were implemented by teachers who had not taken part in designing them. The research highlighted the core role of the teacher in helping to increase the quality of classroom talk (teacher-student and student-student) that helped improve students' understanding of science ideas.

How was this achieved?
Researchers and teachers worked together to produce tools that helped teachers to present the content in a way which addressed known learning difficulties for students. Specifically they focused on students' learning difficulties with some core science topics, including photosynthesis and current electricity. They also explored students' understanding of the nature of scientific knowledge, the procedures of scientific enquiry and the forms of reasoning used by scientists in interpreting evidence and proposing conclusions.

How was the research designed to be trustworthy?
Altogether the research involved over ninety teachers and their classes in more than twenty schools in a network of related research projects. Data about teacher and student learning were collected using multiple complementary sources, including:

- student test data
- classroom observation
- interviews with teachers
- questionnaires and focus groups.

The researchers undertook activities with groups of science teachers and other education practitioners, to design 'diagnostic probes' and to develop, implement and evaluate new teaching schemes based on research about students' understanding and common misconceptions in science. All data relating to students' test results included comparison data from similar classes in which the new strategies were not used.

What are the implications?
The research shows the importance of:

- teachers building on students' common alternative conceptions of science phenomena
- classroom talk that probed and extended students' thinking
- engaging teachers in doing research rather than simply using it
- lesson planning that includes open-ended activities in which students can take more ownership
- creating and sustaining a professional learning culture for schools that engaged with research evidence about science teaching and learning.

What do the case studies illustrate?
The case studies show:

- how teachers used concept maps as diagnostic tools to inform them about their students' understanding of science concepts
- how teachers created and used diagnostic probes to assist them in their planning and teaching
- the development of students' thinking in response to questioning by their teachers
- how systematic rules for discussion helped to improve classroom discussion
- the effect of giving students more ownership of science activities.

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Study

What did the research find out about teaching and learning in science?
The findings include the following eight key points:

- diagnostic probes helped teachers find out where their students were starting from when they approached core science phenomena
- diagnostic probes provided opportunities for teachers to engage with students about their reasoning in science lessons
- the availability of diagnostic probes led to more discussion in class, which stayed well focused on the key ideas probed; several teachers reported that the probes helped them teach topics outside their science specialism with greater confidence and in more interesting and interactive ways
- increasing the time and attention paid to points of known learning difficulty paid off in better understanding of the explanations for the phenomena being studied
- increasing the quality of classroom talk (teacher-student and student-student) helped to create better understanding of scientific phenomena
- many teachers were uncomfortable teaching about the nature of science processes and often omitted treatment of it in the face of pressures arising from teaching science curriculum content
- the effectiveness of teaching the nature of science was related to teachers' own understanding, to their views of the teachers' role in science lessons and to their ability and willingness to adopt less transmission-focused methods
- teachers agreed with the idea that research could inform their practice but often felt that its findings were not credible to them or not presented in a form which was useful.

In the following sections of this RfT we present more details about the work carried out by teachers and researchers in the four project areas.

What were the ideas about students' thinking in science which underpinned the research?

- From their analysis of previous research, the researchers suggested that difficulties in the teaching and learning of science were often related to students' misconceptions of science. They went on to add that many misconceptions arose from the everyday concepts of science students brought to school and the language they used to describe them. The researchers started from the project team's premise that research about students' talk about science indicated the following problems:
- Students draw on their existing concepts to explain simple, scientific events using frameworks of ideas that are often very different from the accepted scientific knowledge at the time. These frameworks are remarkably resistant to change.
- Some misconceptions in students' thinking about scientific phenomena reflect the use of two different languages - a pre-instructional social one which students bring with them and which is more or less shared by the whole group of learners - and a more formal and precise scientific one. The teacher has to help move the students from the former towards the latter.
- The everyday notions can persist for considerable periods of time. Previous research (see Driver in Further Reading has noted, for example, that students of different ages all (incorrectly) drew on the idea of 'suction' rather than the scientific concept of differences in pressure to account for related phenomena such as the behaviour of a liquid when somebody drinks it through a straw.
- Students' misunderstandings arise from:
    - explaining science phenomena using everyday ideas and processes such as 'suction' rather than the underlying causes such as air pressure difference. Students explain photosynthesis in plants as being analogous to animals' feeding
    - lack of understanding of the forms of reasoning used in science, leading to inappropriate or inconsistent use of science ideas; and
    - gaps in factual knowledge, such as not regarding air as a real substance with a mass.

The research summarised in this RfT related to an exploration of students' misconceptions about scientific phenomena and to the difficulties students' find in using the methods of science, and the ways in which teachers could build on the everyday ideas about science that students brought into their classrooms.

Bringing out students' prior understandings: what are diagnostic probes and how did teachers use them?

Teachers and researchers worked together to create a tool (a bank of diagnostic probes) which aimed to enable teachers to:

- more easily collect data about their students' learning so that they can adjust their teaching as necessary
- provide ready feedback to students about their knowledge and understanding.

The researchers:

- worked with a group of teachers to develop a bank of diagnostic questions that could be used easily by teachers to monitor and evaluate pupils' learning in four important science topic areas (electric circuits; forces and motion; matter and chemical change; biochemical life processes (digestion, respiration, photosynthesis))
- used these questions to explore the progression in understanding of a large sample of pupils aged 9-16
- explored, with a panel of teachers, how the diagnostic question bank could be used to support their teaching and enhance student learning.

Two tier probes were designed - the first question asked for a prediction about what the student would expect to observe in a given situation, the second then asked for the best explanation for this. Other questions probed the consistency in students' use of an explanation in different related contexts. Some questions were more open-ended and many were designed for group discussion.

Twenty teachers provided evidence about how they had used the probes and the impact which they had on their teaching. They used them to:

- rapidly assess the understanding of all the students in a class
- stimulate small-group and whole-class discussion
- teach the subject matter in a more interactive way - particularly when they were teaching outside their own subject area
- clarify their own ideas about the subject matter.

More than half of the teachers agreed that the probes stimulated discussion in their lessons to a greater extent than they had managed to do previously. One teacher commented favourably that the probes lent themselves to 'a much more interactive, discursive approach....a style of teaching I prefer...perhaps I haven't been confident in physics before to risk it. This has given me an impetus.'

An example of a diagnostic probe is presented later in the RfT.

In the case study section of this RfT we look at the way a teacher used concept maps for diagnostic purposes.

Colleagues may like to read a case study about diagnostic probes developed and used by a group of teachers.

What did diagnostic probes tell teachers about their students' thinking?

Drawing on evidence provided by students' responses to the probes the researchers found that students' understanding of some basic ideas of science was quite low and often increased little with age. Specifically they reported that:

- fewer than 50% of students at age 14 appreciated that electric current is the same at all points of a series circuit, and the figure was about the same among 16 year olds
- fewer than 25% of 14 year olds showed good understanding of forces on objects moving with constant velocity or slowing down
- only about 50% of 14 year olds understood that mass is conserved in physical and chemical changes (this rose to 60% at age 16)
- fewer than 50% of students aged 14 were able to successfully apply the particle idea of matter to a range of physical and chemical situations.

The two tier probes showed that many of the students who used a scientific model correctly to predict the current in a series circuit did not do so in a second context. The researchers found this was also the case in other areas of science including the idea that mass is conserved in all physical and chemical changes including photosynthesis. This suggests that many students' knowledge is insecure and their thinking often focuses on surface features, rather than the underlying general principles.

Did new science teaching approaches work any better than the usual ones?

In a second, linked project the researchers worked with teachers to design and then evaluate new teaching sequences based on a detailed understanding of when and where students were most likely to hold misconceptions about science. They explored the impact of new teaching sequences on students' knowledge and understanding of:

- plant nutrition
- changes in matter in terms of particles
- behaviour of simple electrical circuits.

The researchers found:

- in all but two of the 17 intervention classes, between 20% and 74% more students offered explanations more consistent with science principles than students in control classes
- teachers who had been involved in the design stage generally achieved larger improvements in results than the teachers who used the new sequences, but had not been involved in their design. The latter group, however, also achieved significant improvements in student learning
- teachers thought that the new teaching sequences were better at covering curriculum content objectives than the usual approaches
- teachers reported that their students found the new approach more enjoyable than other approaches
- teachers used more conceptually-focused talk when they used the new teaching schemes
- there were no significant differences on test questions requiring only factual recall between the students taught using the new sequences and those following the school's usual teaching approach to the topic.

Each sequence was specifically designed to address a common misconception held by students in each of the key topics considered. These misconceptions have been identified by a number of empirical studies. (See, for example, Andersson (1991), Driver et al. (1993), Canal (1999)). The researchers measured students' learning using sets of diagnostic questions covering content from the national curriculum for science. They evaluated the teaching sequences by collecting pre- and post-intervention data from classes taught by teachers who had participated in the design of the new teaching sequences (7 development classes) and also from the classes of other teachers who had not been so involved (10 'transfer' classes) but who had used the new sequences. All results for intervention classes were compared with those of students in classes which followed the school's usual teaching approach to these topics.

The researchers concluded that whilst there were undoubtedly teacher effects - no two teachers taught exactly the same way even when provided with the same material - the teaching sequence did matter and that when teachers specifically taught in a way which addressed their students' misconceptions and encouraged students to talk about their developing understandings, students' learning improved.

How did teachers and researchers aim to build on students' existing understanding?

Establishing where students are coming from

To tackle this problem teachers and researchers worked together to develop an approach which incorporated two specific features:

- the recognition by teachers that science students bring an understanding of science based on everyday ideas and experiences to their lessons
- the underpinning idea that the learning of school science involves students' using language which incorporates accepted science ideas and explanations.

The demands made by the gap between students' everyday science concepts and scientifically accepted concepts - which the researchers call 'learning demand - varies from topic to topic. For example, learning demand is high for the idea that electric current is the same everywhere round a series circuit. Students tend to think that current is 'used up'. The learning demands in relation to understanding photosynthesis in plants are also high. Students try to explain photosynthesis in terms of plants 'feeding from the soil' in an analogous way to animal nutrition rather than in terms of the synthesis of complex molecules from simpler ones.

On the other hand there are other areas where the gaps in knowledge and language are less demanding, for example, in relation to basic ideas about the human skeleton.
How did researchers and teachers use 'learning demand' to plan lessons?

Whilst the researchers maintain that identifying students' learning demand is an essential first step in building an appropriate and effective teaching sequence, it does not itself point to a specific 'best' teaching approach. Nonetheless they suggest that an analysis of learning demand can help teachers make more informed decisions about: the scientific content to be covered. They explored:

- the learning demand of different parts of the material to be covered and the amounts of time they will need
- how to structure the 'story' or sequence - particularly the use of scientific models, and the range of activities needed to support students' learning at different points
- the form of classroom talk most appropriate for specific parts of the teaching sequence - whether teacher-led, closed and directive; whether between teacher and students or among students themselves; whether closed and teacher-directed or open and inviting the use of explanations.

The researchers suggested that planning lessons is unlikely to be a linear process and the identification of learning demand is likely to develop from the teacher's knowledge of the curriculum to be taught and his/her consideration of the ways students think and talk about science ideas.

They suggest too that explanatory theory can either come:

- before the main activities in a lesson to provide a theoretical structure with which subsequent ideas, activities and discussion can be compared and adjusted - this might be suitable when the specific scientific language and its use is particularly important, such as in teaching and learning about current electricity
- towards the end of the activities as a theoretical structure the teacher and students work towards and construct through a variety of classroom activities including observation and measurement.

In this context, explanatory theory might include an analogy which is simpler in conception than the abstract theory. One example is the analogy of bread vans delivering bread, or water flowing round a pipe, to help students conceptualise electric current and energy transfer in electric circuits. Decisions about when to use explanatory theory would depend on the teacher's appraisal of the nature of the students' learning demand.

The researchers worked with nine teachers to prepare three short teaching sequences of 4-6 lessons each in areas that research suggested students found conceptually difficult. Features of the new schemes involved:

- making time and space in lessons for discussion of conceptual matters
- making the order of teaching reflect the key steps in learning
- encouraging different kinds of classroom talk, explicitly linked to the different kinds of learning involved at different stages.

An example of a teaching sequence designed by teachers and researchers working collaboratively is presented at the end of the study section. Common misconceptions and suggested teaching goals are also presented.

We present a case study about how teachers identified and attempted to address students' misconceptions in chemistry.

What kind of teacher/pupil talk supported students' learning?
Suggestions for different kinds of classroom talk were built into the teaching sequences and included:

- teacher talk, for example, when presenting new ideas
- teacher-student talk where the teacher uses open-ended questions in order to provide students with opportunities to try out new ideas, to give the teacher feedback about their students' understanding, and to indicate to the teacher when scaffolding might be helpful
- teacher supporting talk where the teacher uses key questions and offers appropriate responses to students' questions as they develop and fine-tune their ideas.

As students became more confident in their understanding they completed additional activities which required them to apply their new knowledge in related but different contexts. In this phase of the lesson there were opportunities for the teachers to use open-ended talk to develop the idea that scientific theories and models are generalisable and can be used to understand and explain what is happening in a range of contexts.

In one discussion, a teacher asked open-ended questions about electric currents to stimulate reflection. The discussion followed experimental work in which students measured the current in different parts of a series circuit:

Teacher: Can you explain what current is?
Student 1: Electrons
Teacher: And what happens to them when they get to the bulb?
Student 1: They light up the bulb but they still carry on
Other Students come in: ..but they spend their energy in the bulb
Student 1: Maybe it's like a flow of electrons there's not less electrons but they've got less energy.

In this extract the teacher offered students the opportunity to make extended responses. For the teacher the absolute accuracy of the scientific facts related by the students is less important than how they are thinking about the problem.

In case study 4 we show how some teachers worked to improve their students' discussion skills.

What should students know about science processes?
In recent years the science curriculum and its assessment has made many more demands on students' understanding of the processes of science and of the nature of the knowledge that science produces, for example, in assessments of science investigations coursework. This is an area of science which is not usually taught explicitly in a sustained way. Often the understanding and skills necessary for students to generate, analyse and use scientific information are treated separately from the rest of the science curriculum content.

The third project undertaken by the EPSE Research Network attempted to explore what a curriculum to support scientific literacy (and therefore including understanding of nature of science, or ideas-about-science) might look like. The researchers sought views about what should be taught from science education experts including teachers, writers, scientists and philosophers of science. The twenty-three participants were asked to say what they thought all students should be taught about science to prepare them for life in a modern democracy. Nine themes emerged, grouped under three headings:

- nature of scientific knowledge, including:

o science and certainty
o historical developments of scientific knowledge.

- methods of science, including:

o scientific methods and critical testing
o analysis and interpretation of data
o hypothesis and prediction
o diversity of scientific thinking
o creativity
o scientific questioning.

- institutions and social practices in science, including:

o cooperation and collaboration in the development of scientific knowledge.

A curriculum for scientific literacy would include key ideas such as why scientific knowledge is never definitive but always open to legitimate doubt, why and how scientific knowledge changes, how ideas are tested in science, the skills scientists need in order to interpret evidence and build theories and the part played by creativity and imagination. Furthermore the science educators felt that students should understand that science is a painstaking, collaborative, as well as a competitive, activity that often involves international communities of scientists working over long time periods.

In order to explore teachers' confidence and ability to engage students in learning about the methods of science, a number of teachers taught lessons addressing specific aspects of the nature of science. Evidence drawn from lesson observations suggested that:

- students engaged more in the task of analysing data when the task was authentic and they had some ownership
- when teachers were skilful in prompting and cueing, students were able to work together to tease out hypotheses, to sort out causes and effects; and to suggest what to do to test ideas.

In relation to the kinds of classroom activities which were authentic and gave students ownership of the material the researchers reported that students did not respond well when teachers contrived to set up a task as a vehicle for conveying a particular point. The most authentic situations were those in which rather than receiving precise instructions a context was established by the teacher, students were given the tools to explore the problem and were offered the opportunity to participate in open discussions about how to tackle the problem themselves.

Evidence also suggested that many students find it difficult to:

- make predictions based on scientific evidence
- distinguish between an observation and an inference
- communicate in words the information provided by a graph showing a relationship between variables
- use models to explain the behaviour of scientific systems.

To find out about an approach which explicitly aimed at developing students' skills in related areas see our RfT summary 'Cognitive acceleration through science education' (CASE). Whilst CASE is different from teaching the nature of science and is focused on the development of general thinking skills, it does incorporate developing students' thinking about and using variables, looking for patterns and expressing relationships between variables scientifically, and generalising from scientific data. These are features of higher order thinking and of the processes of science.

What can we learn from the teachers' experience of teaching the nature of science?

The research team worked with eleven teachers from Key Stages 2, 3 and 4 in order to develop strategies and materials for teaching the nine themes identified in the study of science education experts' views. Details of data collection are presented later in the RfT and included classroom observation. The researchers looked for patterns in teachers' behaviour and identified five dimensions of practice, which are illustrated in the table below.

Dimension	**Range**	
Knowledge and understanding of the nature of science	Anxious about their understanding	Confident about understanding
Conception of her/his role	Dispenser of knowledge	Facilitator of learning
Use of discourse	Closed and authoritative	Open and dialogic
Conception of learning goals	Knowledge gains	Knowledge gains and reasoning skills development
Nature of classroom discussion	Contrived and inauthentic	Authentic activities owned by students

On the basis of teachers' observed behaviours the researchers suggested that effective teaching of the nature of science was associated with:

- a willingness to facilitate learning rather than to dispense knowledge even if it meant relinquishing some control over the lesson
- a willingness to ask open-ended questions although in some cases teachers reverted to more closed questions
- an emphasis on 'how we know' rather than 'what we know'
- situations in which teachers created environments which offered their students the opportunity to find ways of tackling problems for themselves.

The evidence highlighted considerable differences among the teachers in their positions on the five dimensions, reflecting the beliefs and dispositions of the teachers in the study, the extent to which teachers felt constrained by the syllabus, the nature of the class and the teaching and learning styles the classes were familiar with. In some cases individual teachers were situated largely on the left of the range for all the dimensions but it was also found that teachers who were on the left of the range on one dimension were not necessarily on that side for the other dimensions. The researchers also commented that as their confidence grew teachers tended to move towards the right hand column in their behaviours.

Most teachers found it difficult to relinquish some of their control, but one teacher was happy to do so and made an important point about spending time developing learning seemingly at the expense of the syllabus content:

'It's ok to waste a lesson....you know there is no content in this lesson.... The group [that I've been working with] have done no differently, no worse than any other group that has been through the same course....You can't compress it if it's just squashing a module into [less time] ...but if you get them to do something then use the information, you have actually gained an enormous amount, I think.' (Brenda)

[The researchers add that the lesson did not, of course, have 'no content', but that the content took the form of development of ideas about science, or understanding of ways of reasoning that can be used in dealing with scientific data. This may be 'invisible' to teachers, but is not non-existent.]

Evidence also suggested that for some science teachers the open type of discourse is unfamiliar territory:

'There may be approaches which I would be much more comfortable with if I was say, a history teacher...especially when it's got to do with text or discussion...But...I'm not as skilled in that.' (Mike)

Colleagues may be interested to read a case study about one teacher's efforts to give her students more ownership of their science work.

What did teachers think made science education research both trusted and useful?

In the final project, 'User's perceptions of research', the research team explored the views of 62 teachers of science education practitioners, including teachers, to assess the potential of science education research to have an impact on policy and practice.

The study found that for research to be trusted and useful enough to have an impact on teachers' practice it needed to have:

- convincing findings drawn from studies with clear, rigorous methods which have the potential to be generalisable to other contexts - 'It's not a convincing piece of research when you have such a small sample....And not necessarily with your ordinary, average teacher either' (secondary focus group)
- findings which they could contextualise in their own experience - 'I tend to look at things that I can often relate to as either currently in my practice, or [...] that's happened to me....' (primary focus group)
- direct relevance to their needs and interests - 'It depends on the type of research that's done. If it's on learning styles and thinking styles then it can have quite a major impact. I recently went on a course, not a science course but a learning styles course...and that's had a major impact on the way I teach...' (Samina, primary teacher)
- illustrations of activities which help them relate the findings to their own work - '...we wouldn't look at research first and say "oh there are many improved results, therefore we will do it"' (Hazel, secondary teacher)

- practical implications which are clear to the practitioner - 'In terms of 11-16 work research by Lovell...that students up to the age of 16, the average student is unable to consciously control one variable, so that it pervades a lot of the work I do when we're looking at course work, experimental planning,...' (Richard, secondary teacher)
- accessible, straightforward writing - '[Research findings] can be a little on the impenetrable side. And if they are made accessible then the likes of me and the ordinary teacher can get hold of them more easily.' (Gail, other science education practitioner).

The assessment regime in English schools was seen as a barrier to engagement with research - 'We would have to be less results driven...People who get good results are scared to change in case their results go down.' (Hazel - secondary teacher).

The researchers commented that the teachers set very high standards as regards rigorous methods of data collection and generalisability in reports of educational research, perhaps because of their own training in science methods.

Whilst lack of time and the difficulty of accessing research were widely seen as barriers, personal contacts between teachers and researchers had the potential to significantly increase teachers' engagement with research and the likelihood of its having an impact on teachers' practice. Teachers identified a range of personnel who could link them with the research community including LEA advisors, and ITT or CPD tutors. Meetings and publications of the Association for Science Education were also recognised as offering opportunities for teachers and researchers to exchange ideas. Teachers' engagement with research was also inhibited by the absence of a culture of informing their own practice with research findings.

Teachers found reported research outcomes that had been transformed into curriculum materials, teaching approaches or other useful resources particularly helpful. (The GTC Research for Teachers web feature is an initiative designed to address the problem of teacher engagement by relating findings from research to teaching and learning in the classroom.)

How was the research project designed?
Overall the research involved over ninety teachers and their classes in over twenty schools in a network of related research projects which aimed to explore the potential for science education research to inform policy and practice.

Project 1
The researchers worked with a group of science education practitioners, including twenty teachers, to design diagnostic probes which were:

- readily usable by teachers in their classroom
- constituted a valid and reliable test of children's knowledge, understanding and reasoning
- had the potential to provide teachers with rapid feedback.

Twenty teachers in eight schools implemented the probes and evidence about students' understanding of key concepts and the teachers' use of the probes was collected by:

- students' responses to the probes. The researchers sampled groups of 200 students for all four topics (electric circuits; forces and motion; matter and chemical change; biochemical life processes (digestion, respiration, photosynthesis)) at the ends of KS 2, 3 and 4. Altogether twelve different student samples, each of 200+ students, were involved in this work
- interviews with teachers.

Project 2
The development phase of the study involved collaborative working between the researchers and nine teachers to develop new teaching schemes in biology, chemistry and physics, based on research about students' understanding and common misconceptions in science.

Each of the nine teachers implemented the new teaching sequences in their classrooms and data about the effectiveness of the teaching schemes and the way teachers used them were collected by a number of methods including:

- classroom observation including a video-recording of each lesson
- diagnostic tests to probe students' understanding before and after the teaching sequence - from the intervention classes and from similar classes in the same schools which had not experienced the new teaching sequences
- interviews with teachers.

In the second part of the study thirteen teachers who had not been involved in the development of the teaching schemes used the plant nutrition and simple electrical circuit modules with their classes. A similar range of video and test data was collected as in the development phase of the project, including comparison test data from similar classes in the same schools.

Project 3
In the first part of the study the researchers involved a panel of twenty-three experts in science education including teachers. Participants' views about the content of a science literacy curriculum were collected through a series of three questionnaires. Researchers analysed each of the first and second sets of responses to identify and aggregate responses into themes which subsequently emerged in a consensus via the third questionnaire.

The research team then used a case study approach based on eleven schools to collect data about the way teachers used a number of classroom exercises based on ideas-about-science and how their students responded. During a period of six days, spread across a year, the teachers were helped to understand the themes and to trial materials and share their experiences with their colleagues. All teachers were observed teaching two lessons and the researchers made video-recordings of the lessons. Field notes and other sources of data, including teacher diaries and questionnaires, helped to complement the observation data.

Project 4
The findings of the final project which explored practitioners' views about, and use of, education research, were based on interviews with sixty-two science education practitioners, including:

- twenty teachers with research experience
- twenty-one teachers without research experience
- twenty-one others from a range of backgrounds including policy (QCA, OfSTED, DfES), authors of text books, HEI, LEAs, science curriculum and examiners.

The researchers also collected data from six focus group meetings. All interviews and discussions were transcribed and analysed for themes using coding. To establish reliability more than one person did the coding.

The research projects we have summarised used a collaborative approach to teacher development, involving both teachers and researchers in science education. This strikes a chord with the findings of a recent EPPI review about the impact of CPD on teaching and learning in the 5-16 age range that teachers engage more readily with research in collaboration with other professionals including researchers.

You can read a summary of the review in an earlier RfT, 'The impact of collaborative CPD'.

Filling in the gaps
The research has highlighted the persistence of a number of misconceptions held by students regarding, 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. Have you found any teaching and learning strategies which have worked well on these - or other topics of similar conceptual difficulty - in your own classes? Or have you noticed other misconceptions that it might be useful for researchers to explore?

One message from the research reported in this RfT is that when outcomes are translated into tools and resources such as diagnostic probes or teaching sequences teachers are more likely to use them. Perhaps HEIs could undertake research and development in this area and fund schools and teachers to experiment with a range of research-informed resources? Partnerships between teachers and academic researchers may be the most effective way of doing this. Do you think this would be helpful?

Creating and sustaining learning situations in which teachers relinquish some control to students is a difficult move for many teachers to make. Is this an area which research could explore? Could teachers who have investigated such learning situations help others by reporting their findings? Write to us so we can add to the case studies, at research@gtce.org.uk

One of the implications of this research project is that current assessment practice may give a misleadingly positive impression of students' conceptual understanding in science. Teachers in this study used diagnostic probes to try to get a better measure of their students' conceptual understanding of science and a teacher in one of the case studies used concept maps for this purpose. Are there other possible approaches? Would it be helpful for research to investigate this area? Can you offer case studies of such efforts?

The study suggests that when it comes to developing a curriculum to support scientific literacy, there are significant problems in assessing students' abilities to apply scientific reasoning, for example. The development of the Science 1 coursework component explicitly demands an application of scientific method but experience suggests that it is difficult to teach how to apply scientific methods, the role of models and the evaluation of rival scientific theories. Have you come across any useful approaches to this task? Could you describe them so that future researchers know more about the evidence in schools?

The research identified a lack of suitable assessment material in relation to the nature of science. Is this an area where researchers and schools could collaborate in testing possible approaches?

Implications for teaching

Whilst preparing this summary of the four projects the RfT team noted a number of implications for teachers.

- Collaborative working was a key feature of the research. Would you find it helpful to discuss students' common misconceptions with colleagues in order to make it a key part of lesson planning in your school/department?
- At one point the researchers commented that the absence of a culture which encouraged the use of research findings was seen as a barrier to engagement with research by teachers. Would it be possible for head teachers or senior curriculum leaders to begin to create such a culture by:
    - disseminating key research literature targeted at specific needs and interests
    - engaging in reflective dialogue with their teachers
    - making their school more permeable to ideas, for example, byidentifying a real need and encouraging some of their teachers to forma study or research group to tackle the issue?

- This project showed that actually doing the research was more effective for teachers than simply using it. Whilst research is difficult to carry out in schools because teachers are so busy, small scale actionresearch has been used by many teachers to tackle problems in theirclassrooms. Would it be possible and useful for you to work with acolleague to explore issues related to teaching and learning using peerobservation, for example, related to teacher use of dialogue?
- The study provided evidence that teaching students the nature of science is difficult as so much attention is focused on content. Is teaching and learning the nature of science something on which you and your colleagues might find it useful to collaborate in order to identify and build on best practice, perhaps within a network of schools?
- Would it be possible to build into your lesson planning a number of more open-ended activities in which your students were able to take more ownership, as far as health and safety considerations allow?

What tools did teachers in the projects use? Some examples

What did a diagnostic probe look like?

This is an example of a two-tier diagnostic probe.

*****************diagram****************

The two bulbs in this circuit are identical.

(a) How bright will the bulbs be?

Tick ONE box

[ ] Bulb 1 is lit. Bulb 2 is off.
[ ] Bulb 2 is lit. Bulb 1 is off.
[ ] Both bulbs are lit. Bulb 1 is brighter than bulb 2.
[ ] Both bulbs are lit. Bulb 2 is brighter than bulb 1.
[ ] Both bulbs are lit, with the same brightness.

(b) How would you explain this?

Tick ONE box

[ ] The first bulb uses up all of the electric current, so there is none left for the other one.
[ ] The first bulb uses up some of the electric current, so there is less left for the other one.
[ ] The electric current is shared equally between the two bulbs.
[ ] The electric current is the same all round the circuit.

How a sequence can be built for teaching and learning about electric currents in simple circuits

The learning aims are:

- current is best thought of as a flow of charge
- current flow provides the means of energy transfer
- current is conserved in a circuit
- the battery is the energy store in the circuit
- energy is transferred from the cell to the resistive elements in the circuit and on to the environment.

Students' ideas are likely to include:

- batteries run out
- electricity makes things work
- current, electricity, volts and power are the same kind of thing
- electricity/electric current flows round a circuit through each component sequentially.

The learning demands then focus on a number of concepts including:

- a clear mental model that includes the ideas of charge, current, and energy
- the idea that the current consists of a flow of charges which carry the energy from the cell
- the current starts simultaneously in each part of the circuit when the switch is closed
- the current is not used up but has the same size at any point round a series circuit

- this moving charges model of an electric circuit can be used to predict and explain the behaviour of many electric circuits.

In planning a teaching sequence the researchers suggested that teachers might:

- build on the students' ideas that batteries make things work and that electricity/current flows; (Students could here be given hands on experience of a simple series circuit and work in groups to discuss ideas)
- introduce and support the idea that an electric current is a flow of charges which carries energy from the battery to the other components in the circuit and hence into the environment; (The teacher could present an analogy based on vans (charges) delivering bread (energy) to a supermarket which they can link to the accepted scientific model)
- emphasise that the current is the same size all round the circuit and is not used up; (Students could explore this practically.)
- help students develop a mental model that differentiates between charge, current and energy
- set students more tasks extending the model to other contexts. (Students could explore this practically - this would provide opportunities for students to discuss together and for the teacher to probe and develop their understanding.)

Full details of the teaching sequences are available from the research team at:
http://edupc1130.leeds.ac.uk/research/scienceed/epse_teach_resources.htm

Common misconceptions relating to photosynthesis and possible teaching goals
Teachers in three schools tested a teaching sequence relating to photosynthesis. Based on previous research about students' misconceptions in science they began with characteristic patterns of students' thinking about photosynthesis identified in the literature, including:

- in parallel with their ideas about animal nutrition, students' tendency to think of plants 'absorbing' food from the soil
- confusion between photosynthesis and respiration
- not appreciating the role of sunlight as an energy source
- a lack of appreciation that photosynthesis, like other biological processes, involves chemical reactions
- difficulty in accepting that a liquid (water) and a gas (carbon dioxide) can combine to give a solid (glucose)
- a lack of understanding that the carbon dioxide ultimately ends up in a range of plant food materials.

Consideration of these patterns of thinking and the misconceptions contained in them, the teachers and researchers worked together to set out the teaching goals it would be necessary to incorporate into the lesson plans. They included:

- opening up the students' own ideas about food
- providing students with the opportunity to see that gases do have mass
- demonstrating that although it sounds implausible, gases and liquids can combine to produce solids
- showing that photosynthesis does work by exploring the production of glucose in leaves of green plants
- developing the idea that glucose combines with other materials to produce a range of plant food types including other carbohydrates, fats, proteins and chlorophyll.

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. To share your views with us email: research@gtce.org.uk
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Case studies

The following case studies are for the most start practitioner based and have been selected to illustrate ways in which teachers have explored the key ideas in this RfT summary in their classrooms.

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. To share your views with us email: research@gtce.org.uk

Concept mapping for diagnostic and formative assessment in the classroom?

This case study shows how teachers can use concept maps as diagnostic tools to inform them about their students' understanding of science concepts and to provide starting points for further teaching and learning. In this study a teacher worked with a high ability Year 7 class in a Northumberland middle school. The teacher chose to adopt this approach because:

'I anticipated that concept mapping would have immediate feedback and promote progress because it involves discussion and teaching by the pupils'.

In this small-scale study the teacher set out to see how effective concept maps were in providing information for teacher and pupils about the understanding students brought to a topic - in this case chemical solutions - and how their understanding developed during the course of the topic.

What did the study show?

The teacher reported a number of findings, including:

- changes in the concept maps towards greater sophistication showed improvements in students' thinking
- student participation was higher than usual
- in the case of this unit of study students had improved their attainment by two national curriculum levels over their key stage 2 national test scores.

How were the concept maps developed and used in the classroom?
The project consisted of a number of stages, including:

- grouping of students according to preferred learning styles
- training of students to construct and discuss concept maps
- individual and collaborative work to construct concept maps in relation to the topic chemical solutions
- teacher analysis of concept maps constructed by students at the start of the project (formative) and those produced at the end of the project (summative) including a comparison of summative maps with post intervention test data.

In the training phase students were taught to create a concept map on a familiar topic using eight words, arrow signs and appropriate phrases for linking.

When constructing concept maps about solutions students sorted twenty-four cards displaying the appropriate terms into patterns and stuck the cards into position on a sheet of paper. They then connected up the terms with arrows to show the relevant links and appropriate phrases to describe and explain the link. They worked in groups to discuss and justify their maps. Video evidence suggested that the collaboration involved a lot of discussion among the students and that there was a high level of participation.

How did teachers analyse the concept maps?
To evaluate the concept maps the teacher adopted the hierarchy:

- spoke - a radial structure in which all related concepts are linked to the core concept but not directly to each other

- chain - a linear structure of understanding in which each concept is linked only to those above and below it
- net - a highly integrated and hierarchical network demonstrating deep understanding.

In addition he counted each concept node with two or more branches coming from it and also links between two separate branches. He also counted links between terms/concepts as 'accurate' ('Solvents are usually liquids'), 'incorrect' ('Solutes dissolve solvents') or 'incomplete' ('Evaporation from a solution forms crystallisation - where neither term is explained or explains the other.) Links were also evaluated in terms of their complexity ie whether they could be interpreted as constituting simple factual statements, explanations or examples.

To enhance reliability of data analysis the teacher involved a colleague in duplicate scoring of a selection of concept maps.

How could teachers use concept maps to uncover the levels of students' reasoning?
The teacher suggested that summative test results and concept maps could be used in association in order to identify patterns of students' thinking, including, for example:

- a poor concept map in association with reasonable test performance might indicate that the student is learning by rote and that understanding may not be strong
- a rich map that links concepts correctly but is different from the teachers' views could mean that the student has an original mind.

Students who present poor concept maps and do not do well in tests might well be in a cycle where poor understanding of basic ideas makes it difficult for them to build links between concepts.

How were the data collected?
The teacher used a number of methods to collect data, including:

- video to record classroom processes
- students' results on a questionnaire about learning styles to group them by learning style
- concept maps drawn by students at the beginning and at the end of the study
- post intervention test (from QCA test base).

Reference: Graham, Sandra (2003) Can concept mapping be used to improve diagnostic and formative assessment in the classroom, providing a means of recognising and raising levels of educational achievement in a mixed ability Year 7 Science Class. *Best Practice Research Scholarship*

Using 'diagnostic probes' to identify students' understanding in science

In this study teachers created diagnostic probes to assist them in their planning and teaching, by effectively and efficiently identifying students' levels of understanding within particular areas of science. The study involved 200 Year 7, 8 and 9 pupils from ten classes. The Year 7 and 8 pupils were taught in mixed ability, mixed gender groups, but were grouped by attainment in Year 9. The sample groups were taken from the whole ability range.

The teachers focused on particular areas of science such as: 'inheritance', 'burning' and 'the Earth in space and gravity'. They reviewed previous research on children's understanding in science to identify possible categories of ideas which characterise pupils' thinking in these areas. Probes were developed in each of the chosen areas. These were trialled with a small group of pupils and refined before being used with the main test groups of pupils.

The teachers suggested that diagnostic probes could be used for a number of purposes, including:

- to find out students' initial understanding of a topic
- to assist in planning teaching
- to challenge and stimulate students' thinking.

The 'Earth in space and gravity' diagnostic probes

The teachers created the following five probes for the earth in space and gravity topic to probe their own students' understanding:

- Models - to represent systems in the universe
- Order - to sequence bodies (sun, galaxy, solar system etc) in order of size
- Solar system - to identify what students knew and believed about the objects present in the solar system
- Gravity (ball) - to identify the ideas that students had about why objects fall
- Gravity (objects) - to identify the ideas that students have about the effect of gravity on different objects.

The probes involved a series of activities including questioning children using models of planets and other objects from space, card sorts to create sequences depending on size, questions about bodies found in space and diagrams illustrating gravitational effects which they had to explain.

The teachers found that many of the students:

- encountered a major problem with scale when thinking about the universe and found three dimensional models even harder to use than two dimensional diagrams
- believed that the solar system is the largest system in the universe and believed that galaxies and other stars would be found in our solar system
- did not associate 'falling' under gravity with mass and thought that heavy objects will fall and light objects will not
- believed that gravity does not exist in space and changed their ideas of falling depending on the context - a ball will fall on earth, but will not fall on the moon.

Other students' misconceptions identified by the study

When the teachers used probes for exploring students' existing ideas about inheritance and burning, they found:

- many students related more easily to inheritance in humans than they did to inheritance in plants and invertebrates
- many students believed (incorrectly) that features acquired by an animal early in its life could be passed on to the next generation
- the level of understanding students showed about burning was dependent on their familiarity with burning
- many students confused burning with melting of solids and burning and evaporation in the case of liquids
- the students displayed misconceptions about the conservation of mass during burning.

Reference:

Nixon, David; Kirk, Hilary and Richard Needham, Brooksbank School, Elland, West Yorkshire. (1998) The use of 'diagnostic probes' to aid teaching and learning in science.

Students' conceptions of the transformation of matter

This study explored the way 10-12 year old students thought and talked about matter and it's transformation in both everyday and scientific contexts. In this longitudinal study the researchers, who were also the teachers, were able to track the changes in students' thinking as a result of the introduction of theory and in response to questioning by their teachers. Whilst the study is from Sweden the insights presented in the study will find an echo in UK classrooms. Core findings relate strongly to one of the main themes of the EPSE project, in relation to the language and thinking students employ in science learning. The study showed that all students improved the scientific quality of their responses. Within this overall change the researchers also reported that students developed their own mental models, based on their own experience, to explain scientific phenomena and that these models existed in parallel to newer, more scientific conceptual models, introduced by their teachers. Whilst the students were stimulated into using the more accurate models by their teachers through discussion, they often reverted to their earlier models and this seemed to be at least partly context-dependent.

The research focused on three science content areas:

- particulate nature of matter
- nature of gases
- nature of chemical reactions.

The basic design of the research was to teach students about the particle model of matter and refine it over a period of three years, using teacher-led, peer discussion and experimental work, in the other topics. During this period teachers conducted four interviews with forty students to explore the extent to which they had adopted the scientific model in their explanations of phenomena.

Because of the constructivist approach adopted by the teachers the role of dialogue between teachers and students were crucial. They were able to explore students' views in two ways:

- spontaneous student responses to direct questions by the teacher
- stimulated student responses arising from scaffolding by the teacher.

The researchers suggest that these two positions correspond to Vygotsky's what students can do unaided and what they can achieve with support from a more experienced person, in this case their teacher, which corresponds to work done in the students' zone of proximal development. They justify their use of the second approach so that they can extract as much information as possible about the student's knowledge.

Using the two questioning measures the teachers classified students' responses in individual interviews according to the understanding and use made of the concept 'molecule'. According to the researchers the use of this concept reflected a more generalised understanding of the nature and behaviour of matter than the students' simpler more concrete model of particles as grains of material, which they adopted when they were first introduced to the behaviour of matter. The teachers used a hierarchy of usage of the molecular concept to track changes in students' conceptualisation of matter which included the following:

- do not mention
- stimulated - mentioned in response to teacher
- spontaneously - mentioned on at least one occasion/per interview without prompting
- spontaneously well - mentioned on at least two occasions/per interview without prompting.

In order for the researchers to be confident the students knew something about molecules in addition to the word itself they had to be able to use the term in a way which included any two of the three key ideas:

- all substances consist of molecules
- molecules are small
- different substances consist of different molecules.

After the students had been introduced to the later topics of gases and chemical reactions the teachers looked for more sophisticated talk. For example they wanted students to mention the speed and energy of molecules when talking about gases and they looked for signs of different kinds of molecules interacting to form new substances rather than simply forming new substances. They also used different experimental contexts. For example when exploring students' understanding of chemical reactions they included:

- petrol burning
- an acid reacting with magnesium.

From their analysis of students' responses to teachers' questions they found that:

- in relation to the concept of molecules 18 of 39 students did not mention the concept at the start of the course which fell to 7 by the fourth interview
- while six students used the term spontaneously well at the start which increased to 12 as the project developed
- in the final interview when students were asked to describe what real gases were like only 30% used the concept of molecules correctly even though many more had shown understanding of the idea - this figure rose to 60% when the teacher prompted them
- during discussion about chemical reactions in the final interview 27/40 students correctly used the word interaction to explain the rusting of iron but this fell to 3/40 when students had to explain the burning of petrol.

The evidence from this case study illustrated students' problems with this model. For example, the students used the idea of grainy particles when it seemed easy to apply, such as for iron rusting. On the other hand they found the model difficult to use for other scientific phenomena such as combustion of petrol. Even when students showed correct ideas about molecules, the concept had not taken root sufficiently to become a general concept for tackling a range of phenomena.

Perhaps these observations highlight the dilemma of introducing students to the difficult concept of molecular theory by first bringing in a far less accurate but easier to grasp concrete model.

The evidence suggested that the students were able to accept the idea of models and often brought an imaginative aspect into their own models. The researchers comment that the ability of ten year olds to imagine what things might be like - in their own way - might also make it possible for teachers to introduce scientific models to even younger age groups. There was some evidence that early usage of scientific explanations stimulated later higher understanding.

Reference:

Eskilsson, Olle and Gustav Hellden (2003) A longitudinal study on 10-12-year-olds' conceptions of the transformation of matter. *Chemistry Education: Research and Practice*, 4(3) pp.291-304.

Helping children to use language to learn science

This case study was selected because it provides insights into how teachers helped to create and foster effective classroom discussion among students using a systematic and rigorous approach to rules for discussion. Whilst the study participants were from Year 5, the strategy adopted was one that teachers could adapt for other age groups. A helpful feature of this study was the science context. The study involved training the students in the ground rules of effective discourse and in using appropriate language for thinking together.

To evaluate the impact of the 23 week strategy - called the 'Thinking Together' programme - the researchers compared it's effects on 109 students in target classes with those on 121 students from matched classes in schools with similar catchment areas who had not undergone the intervention, but had studied the same content. The study found that that teaching students to talk together in order to learn improved the quality of student-student interactions in the classroom, significantly raised their attainment on national test questions in science and improved their performance on non-verbal reasoning tests.

What was the 'Thinking Together 'programme?

The researchers' perspective was that whilst teachers fully understood their role in helping children to learn subject knowledge, in normal practice they were less familiar with the idea of teaching students how to interact with each other. As importantly, most children did not come to school equipped with all the skills for discussing, negotiating with each other and seeking to reach agreement. The aim therefore was to train students to discuss effectively.

The teachers of target classes were trained for one day prior to the start of the classroom intervention. Teachers of the control classes did not receive training but were aware that the results would be made available to them at the end of the project.

The intervention programme was based on twelve 'Thinking Together' lessons which aimed to establish among the students a set of ground rules for effective discussion and to make the students aware of the potential of language to help them think. The approach adopted, like the EPSE research, was influenced by Vygotsky's ideas about the role of talk and social interaction in learning.

The first five lessons aimed to create ground rules and an awareness of how the students could generate and participate in 'exploratory' talk. The ground rules included:

- sharing all relevant information
- encouraging everyone to contribute
- respecting others' ideas
- seeking to reach agreement.

The students were encouraged to think about what made a good talker and a good listener. They learnt the words and phrases which invited comments from others and which sought to elicit explanations. They learnt to distinguish between talk and chatter.

In the remaining seven lessons the students were given the opportunity to develop and practice their skills in subject contexts including science and mathematics. In each science lesson a specific skill was targeted in the context of a specific science theme such as investigating materials for soundproofing.

How did students' talking and reasoning change?

Evidence collected by the researchers suggested that students who had been taught to discuss effectively:

- conducted more sustained interactions when working on a common task
- used more sophisticated discursive techniques involving asking each other for information and listening to the answers, probing each other's ideas and building on each other's suggestions
- showed significantly improved attainment measured on science national test questions and non-verbal reasoning tests, for both individuals and groups, compared with students who did not go through the intervention programme.

In order to analyse the quality of student talk, the researchers identified words indicating reasoning was taking place, such as 'I think', 'would, 'because', and so on. They found students' usage of these words had increased fourfold in the target classes by the end of the intervention. They also found a significant increase in the amount of prolonged talk by students. Initially the average number of such utterances (in excess of 100 characters) was one per activity, at the end of the intervention this had risen to forty-six.

This example illustrates verbal interaction among students who are engaged on a computer-simulated experiment into using materials to block out light:

Alana: How much did you think it would be for tissue paper?
Dijek: At least ten, because tissue paper is thin. Tissue paper can wear out and you can see through it, other people in the way and light can shine though it.

Alana: OK. Thanks.
Alana (to Ross): Why do you think it?
Ross: Because I tested it before!
Alana: No, Ross, what did you think? How much did you think? Tissue paper. How much tissue paper did you think it would be to block out the light?
Ross: At first I thought it would be five but second-
Alana: Why did you think that?
Ross: Because when it was in the overhead projector you could see a little bit of it, but not all of it, so I thought it would be like five to block out the light.

In this exchange the children are working cooperatively, sharing knowledge, providing reasons and seeking to reach agreement.

How did the researchers collect and analyse data?
The research team used a wide range of methods to collect pre- and post-intervention data, including:

- pre- and post-intervention video recordings of a focal group in each target and control class (target and control classes)
- video recordings of other children in target schools when engaged on joint tasks (target classes)
- video-recordings of teacher-led sessions (target classes)
- audio-recordings of interviews with teachers and students (target classes)
- students' scores on non-verbal reasoning tests (Raven's Progressive Matrices) (target and control classes)
- students' scores on science national 'optional SATs' (target and control classes).

Whilst the researchers did collect data about the teachers' use of scaffolding they did not report it in this article.

In order to avoid bias in the evaluation of the quality of the talk arising from the target groups' greater familiarity with the material the researchers used fresh material unfamiliar to both target and control students. Analysis of the transcripts was carried out by researchers who had not been involved in the project.

Reference:

Mercer, Neil; Dawes, Lyn; Wegerif, Rupert and Claire Sams (2004) Reasoning as a scientist: ways of helping children to use language to learn science. *British Educational Research Journal*, Vol. 30, No. 3. For an online digest of this study, see further reading.

Implementing student choice in the classroom

The RfT team selected this case study to illustrate how a teacher implemented an approach to science teaching that offered students more choice about what they did in their science class. In this small-scale research project the teacher addressed teachers' willingness to surrender some of their control over learning to the students. This is a step away from the EPSE research which posed the question of teachers replacing some teacher-led activities by processes of collaboration and dialogue in the classroom which were directed more by students themselves. Nonetheless we think it contains some insights into how teachers might make science more credible and real to their students. This is a US case study and it involved a teacher and her class of 27 junior high (13-14 year olds) students, a group she described as 'chatty, animated but unmotivated and slightly underachieving adolescents'. In the study the teacher aimed to explore how students would respond to being given choices in the classroom. She also struggled with the difficult question of the risk involved in relinquishing control of the classroom. Prior to the research her thinking had been influenced by the following experiences:

- her observation that her students did not respond well to academic approaches to teaching and learning
- her awareness of how much she directed her students
- her reading of the writings of Alfie Kohn (Punished by Rewards), for example, 'If learning is a matter of following orders, students simply will not take to it in the way they would if they had some say about what they were doing.'

Whilst the teacher's main aim was to find out about the impact of student choice on the students' motivation and learning, a constant theme was the effect on her own learning both in terms of the effectiveness of the implementation of the new science units she designed and of the effectiveness of her research methods.

What happened in the classroom?
The teacher decided to focus the work on the human nervous system and created the following units:

- brain and central nervous system
- eyes and vision
- scent and hearing
- touch and taste.

The study began with the teacher exploring students' learning styles using Gardner's Survey of Multiple Intelligences. The results showed the students' learning strengths and weaknesses and aroused considerable interest among them. They also informed the teacher that her class were overwhelmingly kinaesthetic and interpersonal in their orientation to learning. During class discussion the teacher encouraged the students to use this knowledge when it came to making choices about the activities in the lessons.

She divided the classroom up into four areas covering the four sub-topics and made available a wide range of activities, including:

- internet sites to visit
- diagrams to label and colour
- experimental work
- cut and paste activities
- creative writing
- standard worksheets.

At the beginning of the project the students had to indicate the activities they wished to pursue and put a tally mark on a sheet so the teacher could make the necessary resources available.

Each student completed a self-assessment sheet for every activity s/he undertook, in order to provide the teacher with insight into why the students chose particular activities, the effort they put into it, what they got out of it and the level of difficulty they ascribed to it.

The first unit was followed by a second on ecology in which the teacher kept more to the established curriculum whilst incorporating two major activities offering students choices:

experimental work on the creation of water and land ecosystems; and
an assignment giving the students the chance to express what they knew what they had learned about ecosystems in a mural.

How did the new approach affect student learning and motivation?
The teacher found that there were a number of positive results for students, including:

- a feeling of being more in control of their learning - 'It [picking our own assignments] was better because we weren't stuck with something (sic) we didn't want to do' (student written reflection)

- more enjoyment in their work - 'I learned more because it was fun' (student written reflection)
- greater participation in activities (teacher observation)
- growth of students' independence (teacher observation)
- more successful learning (assessment).

The teacher also commented that one of the most successful outcomes was the transformation of the classroom as a result of the work her students had produced:

'The interest and motivation in my classroom is amazing...My own students came in and did not go to their seats...They were more interested in taking a stroll around the room to see what was new. They wanted to measure and record observations...They wanted to talk to their classmates about the murals around the room. They brought their friends in to show them what we were doing..'

What did the teacher learn?
The teacher identified a number issues related to her own learning:

- data collection about her students was informative and helped her plan activities
- the students coped with and enjoyed the extra responsibility
- the marking of students' work was problematic - once she put grades on their work students focus began to shift away from understanding to completing the assignment
- the summative assessment method selected by the teacher was most effective when it was in the same style as the methods of teaching and learning deployed in the work in the classroom.

The teacher recognised that her approach conflicted to some extent with the mandatory testing system already in place and consequently there were issues that needed further exploration.

How did the teacher collect and analyse data?
The teacher used a number of methods to collect data, involving both herself and her students. These included:

- teacher research journal
- teacher field notes of classroom observation
- student artefacts: completed models, projects, creative writing
- student surveys
- student self-assessment on completed assignments
- student daily verbal responses
- student written reflections
- student interviews.

She cross-checked students' responses to pre-set questions and answers against additional data drawn from students' free writing in order to remove possible bias. Students' responses were coded by the teacher into positive and negative outcomes. Her own reflections, drawn mainly from her research journal, were coded into positive and negative views. Data collection and analyses were carried out by the teacher.

Reference:

Patty Baize (2003) Implementing student choice in the classroom.

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Further reading

1. What else might I enjoy reading?

Bruner, J. (1986) Actual Minds, Possible Worlds. London: Harvard University Press.

Leach, J. and Scott, P. (2003) Learning science in the classroom: Drawing on individual and social perspectives.
Science and Education, 12 (1), pp. 91-113.

Driver, R., Rushworth, P., Squires, A. & Wood-Robinson, B.(2004) Making sense of secondary science. London: Routledge.

Canal, P. (1999) Photosynthesis and 'inverse respiration' in plants: an inevitable misconception? International Journal of Science Education, 21, pp.363-371.

Andersson, B. (1991) Pupils' conceptions of matter and its transformations. Studies in Science Education, 18, pp. 53-85.

Cordingley, P. (2000)Teacher perspectives on the accessibility and usability of research outputs. A paper presented to the BERA conference, Cardiff University, July 7-9, London: TTA.

Hargreaves, D. H. (1996) Teaching as a research-based profession: possibilities and prospects.The Teacher Training Agency annual lecture, London: TTA.

Hemsley-Brown, J., and Sharp, C. (2003) The use of research to improve professional practice: a systematic view of the literature. Oxford Review of Education, 29(4), pp.449-470.

Driver, R., Leach, P., Scott, C. & Wood-Robinson, B. (1994).Young people's understanding of science concepts: implications of cross-age studies for curriculum planning. Studies in Science Education, 24, pp.75-100.

2. Where can I find out more online?

Outputs from the EPSE project, in the form of briefings, conference papers and some research papers from the network, can be found at:
www.tlrp.org/proj/phase1/phase1bsept.html

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Appraisal

Robustness

This wide-ranging group of research projects aimed to explore some of the ways in which science teachers drew on science education research to enhance their practice and to improve their students' learning. Altogether the four component projects involved over ninety teachers and their classes in twenty schools. The research involved teachers and researchers working together to explore new approaches to teaching and learning of science, such as developing and using tools for diagnostic assessment. Data about teacher and student learning were collected using multiple complementary sources, including: student test data, classroom observation, interviews with teachers, questionnaires and focus groups. The researchers worked with a group of science education practitioners, including twenty teachers, to design diagnostic probes which were implemented by teachers in eight schools. Twelve different student samples, from Key Stages 2,3 and 4 each of 200+ students, were involved in this work. Nine teachers undertook collaborative working with researchers to develop, implement and evaluate new teaching schemes based on research about students' understanding and common misconceptions in science. The study found that the improvements in students' learning were also achieved in classes in which the teaching schemes were implemented by another group of teachers who had not taken part in designing the schemes. In all cases data relating to students' test results included comparison data from similar classes in which the new strategies were not used.

Together the projects provided extensive and well-supported evidence that science teaching and learning was more effective when it started with students' everyday understandings of science, then worked towards more comprehensive and scientifically accurate concepts. The researchers highlighted the part played by open-ended questioning by the teacher and collaborative working among students in helping students develop their scientific thinking and improve their scientific language. Importantly, the study found evidence that teachers were more likely to use findings from research when they were first transformed into useful tools and strategies.

Relevance
The findings of the research relate to science teaching and learning at key stages 3 and 4. However, the messages contained in the reports - about the language of science teaching and learning, the use of discussion in lessons and about the way students form concepts in science - are also relevant to practitioners who teach science in other phases.

Applicability
The research contains many illustrations of classroom interactions in science classrooms which teachers will be able to relate their own experiences. There are also examples of diagnostic probes and approaches to science teaching and learning which are based on research evidence about the way students learn science. Science teachers will find the work of the EPSE team will help them to reflect on how they can build on their students' talk about science when planning approaches to teaching.

Writing
On the whole, the outputs of the four projects are presented and written in a way that practitioners of science education will find helpful. The longer outputs (in the form of papers and conference presentations) are, in places, geared to an academic rather than a practitioner audience because of the emphasis upon the various schools of thought about students' thinking in science. Whilst the language is relatively jargon-free there are some exceptions, such as the 'Delphic study' approach to collecting research data, which would benefit from greater explanation. The shorter project summaries are more user-friendly and provide overviews which teachers will find useful.Back to top

Research tasters: Five activities

Below are five practical activities developed from ideas in the RfT summary that you could try out in your classroom or laboratory, either on your own or with the help of a colleague.

1. How can we bring out and build on pupils' existing ideas about science?

The RfT study showed that pupils have their own ideas and explanations picked up in their everyday lives, as well as what they have learned in earlier years of school. One example is that plants somehow 'feed' from the soil. The ideas pupils hold can often act as a barrier to more complete learning, but they also offer starting points for alternative, scientific explanations and lively, engaging exploration of ideas.

Investigating learning in your classroom

You might find it helpful to explore what common conceptions pupils bring to their science lessons and how they express them. You will need to identify some of the areas of science where pupils' ideas are likely to conflict with the accepted scientific view, such as, plant nutrition or electric circuits. Alternatively, you could ask pupils to make a drawing, cartoon or flow diagrams to represent their ideas and invite them to discuss them. You could record details of pupils' discussion of one of these key areas, including:

- How many pupils offer views?
- What are the key features mentioned by pupils?
- Do pupils use science terms and concepts in their discussion?
- Do other pupils agree with explanations put forward by other pupils?
- To what extent and what kinds of justifications do pupils present?

When you reflect on the evidence what kinds of patterns do you notice? Are there key phrases that seem to occur regularly? What kinds of evidence do they offer to support their views? Which ideas do pupils find it difficult to respond to?

Next steps

What might you do to try to address pupils' alternative conceptions? Would it be helpful to make explicit one or more alternative conceptions offered by pupils? Would it be a good idea to get the pupils to work in groups on an experiment that challenges an alternative conception?

2. Could you do more to find out about pupils' learning difficulties in science?

The RfT study highlighted that science learning was more effective if teachers planned for and spent time addressing areas of pupils' learning difficulties, such as, plant nutrition, the conservation of energy or the particle model of matter.

Investigating learning in your classroom

Identifying such areas in advance can help you plan your lessons. You may find it useful to explore what your pupils find difficult and how you respond to their difficulties in a particular lesson. One approach might be to:

- choose three 5-minute periods - at the start, middle and end
- use a question sheet with multiple choice answers to provide a basis for class discussion - it might be a good idea to have different types of questions, including ones that relate to new knowledge, applying previous knowledge in new contexts, and building on previous knowledge
- record how you handled your pupils' responses, or perhaps ask a colleague to do so

What were the particular learning difficulties shown by pupils? Were there any patterns in the responses? How far did pupils' learning difficulties reflect conceptions of science based on their everyday lives? How often did you respond to their learning difficulties? Did your responses extend or close down the discussion?

Next steps

You might like to focus your planning on taking areas of learning difficulty for pupils into account. Would it be useful to you to build into your lesson plan specific indicators of where the difficulties are likely to arise, the form they are likely to take and how you might respond? Would you find it helpful to do this in partnership with a colleague, perhaps of a different age group, to expand your knowledge of patterns of learning difficulties?

3. How might we make our questioning more effective for learning?

The RfT study suggests that the kinds of questions teachers ask their pupils has an important bearing on whether the question provides an opening for learning. Open-ended questions are helpful because they enable teachers to find out about the pupils' everyday understanding of, for example, plant nutrition or forces. Pupils benefited when teachers probe their reasoning irrespective of whether their answer is right or wrong.

Investigating learning in your classroom

You might find it helpful to consider question-answer interchanges in your lessons. You could record a lesson, or a part of one, or ask a colleague to observe for you, using the following questions:

- Is the question factual or explanation-seeking?
- How many pupils seemed ready to respond?
- Did the teacher allow pupils time to respond?
- Did the teacher prompt pupils to give make further contributions?
- Did the teacher invite other pupils to respond to what other pupils were saying?

What are the relative proportions of questions of a factual kind to those seeking explanations? How often did the teacher's response invite further discussion? How did the teacher handle pupils' 'wrong' answers?

Next steps

If you are using a much higher number of factual questions than explanation-seeking ones what could you do to redress the balance? Would it be possible to turn some factual questions into ones that probe pupils' understanding more deeply by using the question stem 'What do you think would happen if....?' Or 'Would it be fair to say that?'

If you are aware that in the hurly burly you give pupils less time to respond than you would like, perhaps you could explore the effects of pausing before you reply? Could you try to open up discussion by prompting pupils to 'Go on...' ?

4. How might you use classroom talk to support pupils learning more effectively?

The researchers found that consideration of the uses and the different types of classroom talk set out below had a key part to play in teachers' planning.

Investigating learning in your classroom

You could start by exploring the kinds of talk you encourage and use in different parts of your lesson. One way of classifying the types of talk is to use the categories: presenting content, explaining, discussion/probing understanding and supporting. It might be helpful to use a table to collect information in a table like this:

Task	Type of teacher talk	Purpose	Time spent
result	result	result	result

What type of talk was most in evidence? What type of talk helped pupils develop their understanding? How well matched were the types of talk and the purpose of the talk?

Next steps

Were there occasions when you could have used discussion/probing to enable pupils to construct their own understanding rather than your relying on telling pupils? To enhance pupils' skills in discussing would it be helpful for you to model the kinds of questions they could ask each other? Could you do more to plan your lesson so that discussion and supportive talk were related to specific activities? You might like to involve students in exploring the kinds of talk they use, using a similar grid and to work together to expand the type of classroom talk.

5. What might you do to help pupils gain a better understanding of how science works?

The research findings suggest that whilst pupils enjoy science investigations they find it difficult to interpret and apply the processes enshrined in the 'scientific method' as a whole.

Investigating learning in your classroom

You might like to start by considering how much you know about your pupils' understanding of what they have to do in a science investigation. Recording a science investigation lesson would enable you to spend time analysing the main points. How well did your pupils understand the different stages of a science investigation:

- What are you trying to find out out?
- What do you think will happen?
- Why do you think this will happen?
- What would you do to find out?
- What could you measure?
- What do your results tell you?
- How do you explain what happened?

Which of these stages did your pupils find the most - or the least - difficult?

Next steps

After analysing which stages and aspects of scientific method pupils did and didn't find difficult, you might find it helpful to break down the skills your pupils need to develop, focusing on the things they found most difficult. Would it be useful to them if you spend time discussing each skill in turn emphasising the questions listed above? Would it give them a better idea of the skills involved if you demonstrated what they need to do and gave them small-scale experiments in groups with which to test out and practice the skills?

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