Teaching and Learning RESEARCH BRIEFING

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Towards Evidence-based Practice in Science Education 3:

Teaching Pupils 'Ideas-about-science'

Recent international debate has suggested that the primary aim of school science should be 'scientific literacy'. In addition to knowledge of the content of science, this also implies an understanding of the nature of scientific knowledge, its production and communication. Yet, there is little academic consensus about this element. A Delphi study was therefore used to explore the extent of agreement amongst a diverse group of 'expert' stakeholders, leading to an investigation of the nature of the challenge which teaching these ideas poses for teachers of science.

- There is agreement amongst 'experts' on key themes about the nature of scientific knowledge and its production which should be included in the school science curriculum. → Most, if not all, school science curricula will need to change and adapt to incorporate these themes to meet the aim of teaching for scientific literacy.

- Teachers' ability to teach these key themes is dependent on several interrelated capabilities, of which an understanding of the nature of science is only one. → Changing the science curriculum to meet the demands of scientific literacy will require a significant investment in the professional training of teachers of science, in particular, on how to identify appropriate learning goals and manage a more discursive teaching approach.

- Written probes to determine student understanding of these key themes are still in their relative infancy. Whilst those that do exist provide some useful insights on pupils' understanding, more work is needed to improve both their validity and reliability. → The means and manner of assessment is a strong determinant of not only what is taught but also how it is taught. Developing effective items which test these key themes, and promote higher order reasoning and evaluation, requires further research and development.

The research

The EPSE Network

This project is one of four undertaken by the Evidence-based Practice in Science Education (EPSE) Research Network. The Network is a collaboration involving the Universities of York, Leeds, Southampton and King's College London. Its overall aim is to explore ways of enhancing the impact of research on practice and policy in science education by improving our understanding of the interface between researchers and practitioners. The EPSE Network has developed and evaluated several examples of evidence-informed practice, and has explored practitioners' perceptions of the influence of research on their practice. Whilst focussing on science education, the findings and outcomes may also illuminate the research-practice interface in other subject areas.

Background

The increasing significance of science in society has led to questions about what kind of science education is appropriate for the majority of pupils, who will end their formal education in science at age 16. The report *Beyond 2000: Science Education for the Future* (Millar & Osborne, 1998) is one stimulus to this debate in the UK, and similar debates are taking place in many countries around the globe. One general point emerging is that we can no longer continue to offer a science education whose primary function is a pre-professional preparation for future scientists. Rather, it is important also to teach young people something *about* science – commonly termed 'ideas-about-science' – as well as developing an understanding of the major concepts of science.

Yet what should be taught, and how should it be taught? These are questions which this project sought to answer. Until now, there has been little academic consensus about the nature of science and scientific work, which has resulted in an acrimonious debate dubbed 'the science wars'. If academics who are engaged in either the practice of science or the study of its practice cannot agree, how can science teachers be expected to teach this aspect of science?

Project Aims

The aims of this project were:

a) to determine the extent of 'expert' consensus about learning targets for the processes and practices of science for pupils of different ages, and the expected pupil performances that would indicate the attainment of those targets.
b) to develop and evaluate teaching materials to improve pupils' attainment of the learning targets identified.

The Delphi Study

We addressed the first aim by conducting a Delphi survey of the views of 23 acknowledged experts on science communication, including scientists; science teachers; science educators; historians, philosophers and sociologists of science; and people involved in the public understanding of science. Using three rounds of questionnaires, each successively amended in the light of previous responses, and where the identity of the other participants was not known to the others, we sought to identify the extent of agreement amongst these experts. Our findings showed that there was a strong consensus about nine common elements of 'ideas-about-science', or 'themes', that should be part of the 5-16 science curriculum. These are summarised in Figure 1.

Working with teachers

In the second phase of the study, we worked with eleven Key Stage 2, 3 and 4 teachers to develop a range of strategies and materials for teaching these nine themes. Teachers were recruited from the London area, using previous contacts or recommendations. Six days were devoted to developing these teachers' understanding of the themes, developing materials and strategies, and sharing their experiences of the variety of approaches they currently tried. We then visited each teacher in their school, and video-recorded two lessons relating to one or more of these themes. Additional sources of data were field notes of lessons and

Theme Title and Summary

NATURE OF SCIENTIFIC KNOWLEDGE

Science and Certainty
Students should appreciate why much scientific knowledge, particularly that taught in school science, is well-established and beyond reasonable doubt, and why other scientific knowledge is more open to legitimate doubt. It should be explained that current scientific knowledge is the best we have but may be subject to change in the future, given new evidence or new interpretations of old evidence.

Historical development of scientific knowledge
Students should be taught some of the historical background to the development of scientific knowledge.

METHODS OF SCIENCE

Scientific methods and critical testing
Students should be taught that science uses the experimental method to test ideas, and, in particular, about certain basic techniques such as the use of controls. It should be made clear that the outcome of a single experiment is rarely sufficient to establish a knowledge claim.

Analysis and interpretation of data
Students should be taught that the practice of science involves skilful analysis and interpretation of data. Scientific knowledge claims do not emerge simply from the data but through a process of interpretation and theory building that can require sophisticated skills. It is possible for scientists legitimately to come to different interpretations of the same data, and therefore, to disagree.

Hypothesis and prediction
Students should be taught that scientists develop hypotheses and predictions about natural phenomena. This process is essential to the development of new knowledge claims.

Diversity of scientific thinking
Students should be taught that science uses a range of methods and approaches and that there is no one scientific method or approach.

Creativity
Students should appreciate that science is an activity that involves creativity and imagination as much as many other human activities, and that some scientific ideas are enormous intellectual achievements. Scientists, as much as any other profession, are passionate and involved humans whose work relies on inspiration and imagination.

Science and questioning
Students should be taught that an important aspect of the work of a scientist is the continual and cyclical process of asking questions and seeking answers, which then lead to new questions. This process leads to the emergence of new scientific theories and techniques which are then tested empirically.

INSTITUTIONS AND SOCIAL PRACTICES IN SCIENCE

Cooperation and collaboration in development of scientific knowledge
Students should be taught that scientific work is a communal and competitive activity. Whilst individuals may make significant contributions, scientific work is often carried out in groups, frequently of a multidisciplinary and international nature. New knowledge claims are generally shared and, to be accepted by the community, must survive a process of critical peer review.

Figure 1 Understanding the Nature of Science; Nine key themes teachers' meetings, instruments to elicit the teachers' views on the nature of science, and interviews conducted with the teachers before and after teaching the lessons. The lessons were then summarised in a set of lesson transcripts and the data examined iteratively to search for major themes and patterns that characterise effective teaching of ideas about science. Emerging from the eleven case studies was a set of five dimensions of practice which distinguished the ability of the teachers (Table 2). These dimensions are not mutually independent nor are they intended to uniquely position any teacher. Rather, they are an interpretive approach to diagnosing and explaining the differences in practice we observed. Our findings suggest that when teaching the themes a teacher's understanding of the nature of science was less significant than might be expected. Rather, the teacher's pedagogical style and beliefs were at least as important. In particular, teachers' ability to structure and facilitate more open dialogic questioning in the classroom was paramount.

The original aim of evaluating the effectiveness of specific materials proved impossible because: a) the teaching schemes followed by teachers were a heterogeneous mixture of topics, and b) there was enormous variation in practice between teachers. The combination of these two factors far outweighed the effects of any specific materials. Moreover, measuring effectiveness through pupil tests was problematic, as the domain suffers from a lack of expertise in testing student understanding of 'ideas-about-science'. Consequently, items lack reliability, validity or both. Hence, the locus of our enquiry became: what were the elements of effective practice when teaching about science? Effectiveness in this case was measured by evidence of pupils' engagement with 'ideas-about-science' – that teachers were creating opportunities for students to ask (and try to answer) their own questions, and by providing space for pupils to develop their own understanding, rather than emphasising the 'right answer'. Such teachers recognised that there was a cognitive, epistemic and social dimension to learning goals as well as a conceptual one. Answering our reformulated question has helped us identify the kind of professional training and support needed to develop the practice of teachers of science to meet the challenges of new science curricula such as *21st Century Science*.

Major implications

The implications of this study are threefold.

First, this work has contributed to establishing that there is agreement amongst those with in interest in science education about the components of a 'vulgarised' account of science. This finding is important in contradicting the argument that such elements should not be included in the school science curriculum as there is a lack of consensus about them within the academic community. Our data show that whilst the account provided by the key themes emerging from the Delphi study may not be comprehensive or complete, it does include significantly more components and elements than are addressed by most science curricula. These findings have had an influence on current QCA proposals for revision of the Science National Curriculum, and on the formulation of the *21st Century Science* course which is currently under development.

Second, our work has explored what it might mean for teachers of science to address these themes in their teaching. It has shown that the task is more complex than might be envisaged. Whilst an understanding of the nature of science is a necessary condition, teachers, as 'knowledge intermediaries', must transform these themes into an appropriate set of learning goals and adopt pedagogies which permit students the opportunity to explore and reflect on the ideas involved. Our findings suggest that this requires the teacher to see him/herself less as a transmitter of information, reliant on a closed authoritative dialogue, and more as a facilitator of opportunities which enable discursive consideration and exploration by students of the epistemic and cognitive dimensions of science. The latter, in particular, requires a change in the teacher's use of discourse in the classroom. Given that the subject-culture of science teaching is dominated by a view of science as a body of given knowledge, with little scope for argumentative discourse and where plural alternatives are rarely considered, the incorporation of 'ideas-about-science' poses a substantive challenge for the teaching of science. Meeting this challenge will require a significant programme of continuing professional development to support the introduction of any new science course.

Third, our work sought to assess student understanding of these ideas-about-science. This task was undertaken by trawling the literature for items and probes, and through developing our own items. From this process we developed a set of probes which were used but whose results were inconclusive. Whilst performance on these items overall was found to correlate quite well with other assessments of students' knowledge and ability, analysis of responses to over half the items indicated that their reliability was questionable. In addition, comments received from teachers and other science educators suggested that some were of questionable validity, either measuring a component of knowledge and understanding that was too specific, or attempting to assess too broad an understanding with a single item. Our conclusion was that the science of assessing students' understanding of 'ideas-about-science' was still in its infancy. In part, this is because the models of assessment are too reliant on assessing recall or conceptual understanding rather than the cognitive or epistemic understanding which teaching about these key themes sought to address. Hence, there is an urgent need to develop similar tools for this domain.

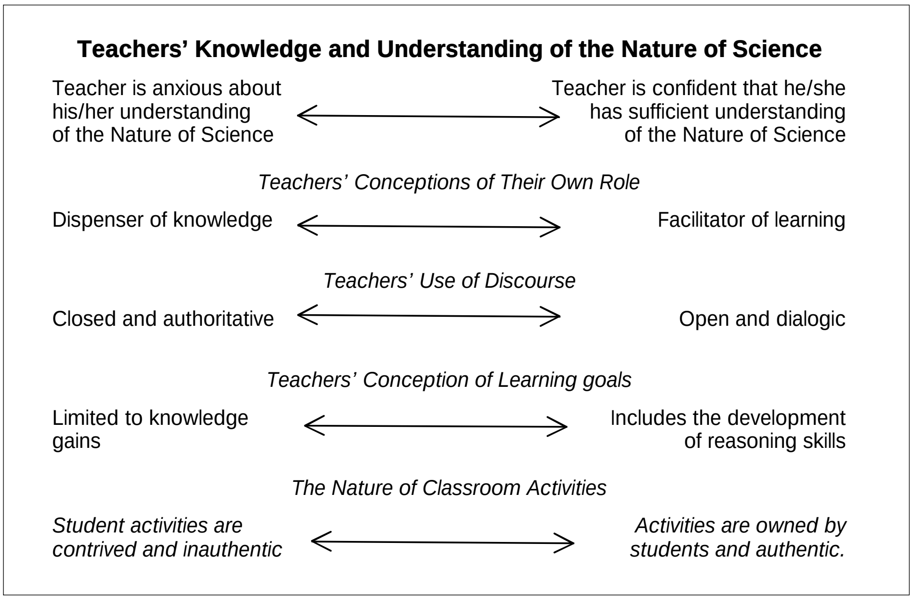

Figure 2 Five Dimensions of effective practice when teaching the Nature of Science

References

Millar, R., & Osborne, J. F. (Eds.). (1998). *Beyond 2000: Science Education for the Future.* London: King's College London.

Further information

Further information on the project, including full text of several articles and conference presentations and a sample of the teaching materials produced, can be downloaded from the EPSE Network website (address below).

For a full report on the Delphi Study, see: Osborne, J.F., Ratcliffe, M., Collins, S., Millar, R., & Duschl, R. (2001). *What should we teach about science?* A Delphi Study. London: King's College.

Further details on the second part of the study can be found in:
Bartholomew, H., Osborne J.F. & Ratcliffe, M. (2002). *Teaching students 'ideas- about-science': Case studies from the classroom.* Paper presented at the Annual Conference of the National Association for Research in Science Teaching (NARST), New Orleans, April.

Items developed for assessing students' understanding of science are discussed in: Osborne, J. F., & Ratcliffe, M. (2002). Developing effective methods of assessing Ideas and Evidence. *School Science Review,* 83(305), 113-123.
A full report, written for the Qualifications and Curriculum Authority, is available from the project website.

A TLRP 'gateway' book, in the *Improving Learning* series, is in preparation on the outcomes of all four EPSE Network projects and their implications for efforts to increase the impact of research on practice in science education. This will be published by RoutledgeFalmer, in 2004. Other articles for academic and professional journals on various aspects of the work are also planned.

The warrant

The range of individuals who responded to the Delphi questionnaire was a comprehensive selection of experts either working in science, studying its practice, involved in its communication, or engaged in science education. The study, therefore, elicited a wide and diverse range of opinions. The results showed that a considerable level of agreement existed around these nine themes, even though some of the participants had been known to disagree publicly on their views of science. Thus we believe that this study has high validity. Its reliability is supported by the fact that many of its outcomes are similar to the consensual views currently emerging internationally in curriculum documents. The findings are shortly (Sept. 2003) to be published in the *Journal of Research in Science Teaching,* the leading international journal in the field.

The outcomes of the second study are based on an extensive and in-depth analysis of a range of data emerging from 11 case studies. The different data sets have permitted triangulation of the data which has enhanced the reliability of the findings. Previous attempts to explore teaching about science have been based predominantly in the assumption that knowledge of the nature of science was the essential precursor to effective practice. In contrast, our study deliberately took a more grounded theoretical position, examining not only teachers' subject knowledge but the translation of that knowledge into learning goals and pedagogic strategies. Hence, this work has offered fresh insights into the pedagogic problems posed by adding this new component to the teaching of science.

EPSE Network website:
http://www.york.ac.uk/depts/educ/projs/EPSE

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Teaching and Learning Research Programme

TLRP is the largest education research programme in the UK, and benefits from research teams and funding contributions from England, Northern Ireland, Scotland and Wales. Projects began in 2000 and will continue with dissemination and impact work extending through 2008/9.

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Outcomes: TLRP studies a broad range of learning outcomes. These include both the acquisition of skill, understanding, knowledge and qualifications and the development of attitudes, values and identities relevant to a learning society.

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Improvement: TLRP develops the knowledge base on teaching and learning and collaborates with users to transform this into effective policy and practice in the UK.

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