Towards Evidence-based Practice in Science Education (EPSE) - an ESRC funded Teaching and Learning Research Network

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The central aim of this Research Network is to improve the interface between science education researchers and teachers, by developing and evaluating several examples of evidence-based practice in science education. The research is being carried out in collaboration with practising teachers in primary and secondary schools, to improve our understanding of the ways in which practitioners draw upon evidence in taking actions and making decisions.
The Network has four inter-related projects. Two focus on the learning of science content: i) how diagnostic assessment can be used by teachers to provide reliable evidence about their pupils' understandings; ii) devising and evaluating short teaching packages, based on existing research evidence, to teach some key ideas in science more effectively. A third project is developing and evaluating materials to improve pupils' learning 'about science', such as their understanding of the scientific approach to enquiry, and of ideas like risk that often feature in media reports about science.
The final project will draw on the experience of the first three to explore with teachers and other practitioners the factors which enable and inhibit the use of research evidence in their work.
This paper outlines the rationale behind the projects and the progress to date.

The aim of the Research Network

Educational research is commonly judged to have little influence on classroom practice. We believe, however, that greater use of findings from science education research on teaching and learning (pedagogic research) can lead to significant improvement in pupil learning outcomes. The central aim of the Research Network is to improve the interface between science education researchers and practitioners, particularly teachers, by developing and evaluating several examples of evidence-based practice, and by improving our understanding of the ways in which practitioners draw upon evidence in taking actions and making decisions.

The relationships between practice, evidence and research

There has been much discussion of the relationship between research and professional practice in many areas. In the context of education, some have argued strongly that, in principle, there can be no general, predictive theories to guide practitioners' actions (Roberts, 1984; Bassey, 1986). In the UK, on the other hand, there has recently been an increasing demand that educational research should provide information on 'what works', in a form that can be applied directly by teachers (Barber, 1999). A recurrent analogy in this discussion is with evidence-based medicine, where practitioners' actions and decisions are based on accepted protocols, supported by explicit evidence (Hargreaves, 1996). The argument is that education should seek to move towards more evidence-based approaches of the same sort.

The actions of teachers and other educational practitioners are, however, influenced by a range of *different* types of knowledge (Brown & McIntyre, 1993, Loughran, 1999), each based on *distinctive forms of evidence* gathered from different sources. First there is specific knowledge of the context in which the practitioner is working, including their knowledge of the other individuals involved. This is seldom formally codified and some of it may be tacit. At the other pole, there are generalised knowledge claims arising from research about correlations and causes, some of which may be theory-based. By their nature, these are abstracted from the particularities of specific settings. As a consequence, it is difficult for a practitioner to judge how far the findings apply to his/her own context. Between these are *accounts of other practitioners' practice*, ranging from informal oral accounts to more formally documented case-studies. These retain specificity and are closer to practitioners' contexts, but require a judgement about how the information might relate to one's own setting.

Much practitioner knowledge is also communicated through established practices, curricula and resources that embody decisions of the community of practitioners (for example, about the timing and sequencing of instruction, and about 'standard' methods and approaches). One consequence of this is that the knowledge becomes tacit and the supporting evidence 'invisible' (Barthes, 1972). Curriculum policy-makers, teacher educators and textbook authors both create, and draw upon, this corpus of 'knowledge embedded in established practices'. These groups are, therefore, also potentially important 'users' of evidence from research, as their articulation of the requirements of practice through curriculum specifications or in widely used texts is a major influence on teachers' classroom actions and decisions.

Knowledge generated by educational research differs from other forms of practitioner knowledge in that it is supported by documented evidence available in the public domain. For this reason it is often seen as of higher status. Yet to many, including practitioners, it appears to contribute little to the improvement of practice (Hargreaves, 1996; Hillage et al., 1998). This might indicate a failure of communication from researchers to practitioners, or insufficient involvement of practitioners in setting the research agenda. Whilst these may provide partial explanations, our view is that more attention needs to be paid to how practitioners receive and interpret research evidence, and how they appraise it in relation to other sources of evidence and to their values, beliefs and objectives.

How research evidence might impact on practice: the Research Network in overview

Perhaps the most useful, and fundamental, kind of evidence in education is evidence of whether a pupil has, or has not, learned what we wanted him or her to learn. Valid and reliable instruments for obtaining this evidence enable teachers to make better-informed judgements about the effectiveness of their current practices. Such instruments *do not*, however, at present exist for assessing pupils' learning at school level in any of the main science domains. For although previous surveys (such as those of the APU and TIMSS) have assessed performance across the sciences, they have not provided diagnostic instruments for more detailed assessment of learning in specific domains. Yet domain-specific information is necessary for the planning of effective learning experiences. Other research studies have, however, provided considerable evidence of common misunderstandings in many science domains (Driver et al., 1994). One aim of <u>Project 1</u> (of the four interrelated projects), then, is to develop instruments, based on research findings, for assessing learning in specific science domains, at levels corresponding to Key Stages 2-4. Working closely with a small group of practitioners, we will use these to collect baseline data on pupils' understanding in some key domains, from current teaching, and explore how teachers' practices change when they have access to better and more detailed evidence of pupils' understanding of major science ideas.

Project 2 starts from evidence of pupils' current understanding in some key science content domains, and from hypotheses drawn from the current research literature about how this might be improved. We are working with a group of teachers to develop and evaluate short teaching 'packages' designed to improve pupils' understanding of some key ideas. In particular, we will use these to study in detail the factors which are important in implementing such 'packages' in the classroom, and in extending their use to teachers not involved in their development.

Project 3 complements projects 1 and 2 by looking at pupils' *understanding of the processes and practices of science*. Whereas there is broad consensus about intended learning outcomes for the main content domains of school science, there is much less agreement about this aspect of science learning, though it is widely recognised to be important, not least for public understanding of science. There is also less clarity about the kinds of performance by pupils which can be taken as evidence of understanding. So the first phase of Project 3 tests any emerging consensus within science education on learning objectives in this area (Driver et al., 1996; Millar & Osborne, 1998), using a Delphi study with a panel who bring a wide range of relevant experience and expertise. This will provide a valuable point of reference for curriculum discussion in the future. Project 3 will then develop and evaluate instruments for assessing the main learning outcomes identified through this Delphi exercise. We will then work with a group of teachers to develop and evaluate some short teaching interventions to improve pupils' understanding of some key 'ideas-about-science'.

The focus in Projects 1-3 is therefore on the impact on pupil attainment of teaching approaches based on research evidence. The projects will produce instruments of high quality for monitoring pupil attainment, along with some examples of evidence-based teaching approaches, each with evidence of its effectiveness in promoting improved pupil attainment in specific areas of the curriculum.

There is considerable evidence that practices based on research evidence cannot be imposed on teachers, but can only be initiated by researchers working in collaboration with teachers who are seen as co-researchers (Baird & Northfield, 1992; Huberman, 1995). Projects 1-3 will, therefore, be carried out in partnership with groups of practitioners, who will contribute to the design of the project, the collection, analysis and interpretation of data, and the dissemination of outcomes. As a consequence, these projects will provide extensive data on the relationship between research evidence and practice, as each is, in effect, a case-study of the research-practice interface. Project 4 will then use the extensive data collected during projects 1-3, together with further data from interviews and focus groups, to explore directly the views of a wider and more representative group of teachers and other key practitioners in science education on the relationship between research and practice in science education. Table 1 shows the aims of the four interrelated projects.

Table 1 Aims of the four research projects in the EPSE network

Project	Aims	Based at
1	*Using diagnostic assessment to improve pupils' performance in science* a) To develop, in collaboration with various user groups, a set of diagnostic tools and assessment strategies for monitoring the progression of pupils' understanding in some important science content domains, based upon evidence in the research literature; b) To investigate how teachers' practices change as a result of using these diagnostic tools and assessment strategies, and to evaluate the impact of such change on pupil learning	York
2	*Issues in the implementation of evidence-based approaches* a) To investigate, from the perspective of teachers, the issues involved in developing and implementing instructional approaches based on research evidence, in particular issues associated with implementation by teachers not directly involved in the development; b) To understand better the range of influences which shape science teachers' classroom decision-making, and the ways in which these are likely to influence the uptake of evidence-based practices; c) To evaluate the effectiveness of evidence-based approaches in science in enhancing pupils' learning	Leeds
3	*Teaching pupils 'ideas-about-science': clarifying learning goals and improving pupil' performance* 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.	King's College London
4	*Understanding the researcher-user interface* a) To obtain a better understanding of the extent to which teachers, and other user groups, recognise and make use of research findings in the course of their normal practice; b) To explore the factors which promote and inhibit the impact of research on science teaching and learning on practice; c) To investigate some possible models for the involvement of teachers in shaping research agendas and identifying research priorities.	All four centres

Progress to date

While all of the first three projects are underway, progress with project 3 is discussed here as the first phase of this project is almost complete.

Background to Project 3

Recent arguments in science education have proposed that school science should pay more attention to teaching epistemic aspects, such as the nature of science and 'ideas-about-science'. (Duschl, 1990; Millar & Osborne, 1998; Jenkins, 1999). The political and moral dilemmas posed by contemporary science require an understanding not only of the content but also the processes and practices of science (Irwin, 1995; Collins (in press)). These include an understanding of the value and limitations of empirical evidence, the means by which scientists generate reliable knowledge, probability and risk, and the ways in which knowledge claims are scrutinised by the scientific community (Fuller, 1997; Newton, Driver & Osborne, 1999). There is well-established agreement in broad terms of the science content of the school curriculum. However, there has been little empirical exploration within the science education community about what 'ideas-about-science' are essential elements of contemporary science teaching. In part, this is a consequence of a community whose normative values have prioritised knowledge over process. A survey by Alters (1997) of 187 members of the Philosophy of Science Association found that there 'is no one agreed-on philosophical position underpinning the existing nature of science in science education'. The findings of this study were contested by Smith et al. (1997) who argued that the items used had been pre-selected as those issues for which there was *no* consensus. In addition, the participants were only a narrow sample of those engaged with science communication and had a modus vivendi that relied on professional disagreement. McComas and Olson (1998), in contrast, argue from their analysis of 8 standards documents from the USA, England, Australia, New Zealand and Canada that there is measure of consensus about the basic messages that should be communicated. However, evidence exists that the existing limited treatment of the processes and practices of science is poorly taught (OFSTED, 1999).

The first phase of this project sought to establish whether there is any consensus amongst 'experts' on what constitutes essential elements of the processes and practices of science for the 5-16 curriculum. To the extent that consensus *does* exist, the outcomes would carry authoritative weight as a systematic enquiry into the key targets for school science. In terms of the distinction between the 'intended', the 'implemented' and the 'attained' curriculum (Goodlad, 1975; Robitaille et al., 1993), this process would provide an empirical underpinning for the 'intended' curriculum.

Methodology

In this context, we sought to define 'experts' broadly as those with acknowledged expertise in implementing, communicating or researching the processes and practices of science. In essence, we sought to represent the views of the whole community engaged in defining and communicating the nature of science. Thus we sought views from leading scientists; science teachers; historians, philosophers and sociologists of science; science educators; and those engaged in the public understanding of science. Criteria used in selecting 'experts' included: membership of the Royal Society; books and publications; national awards for teaching. The common element shared by the group was an interest in communicating ideas about science either in their writing, teaching or other work - all in essence having an experience of acting as 'knowledge intermediaries' between science and its publics.

A process in which group tacit knowledge about the processes and practices of science is elicited and exposed to group scrutiny was chosen to examine experts' views - a three-stage Delphi study (Clayton, 1997; Murry & Hammons, 1995). Delphi studies have been used in other curriculum-based explorations (Haussler et al, 1980; Blair & Uhl, 1993; Doyle, 1993; Smith & Simpson, 1995). The Delphi method aims to improve group decision-making by seeking opinions without face-to-face interaction and is commonly defined as 'a method of systematic solicitation and collection of judgements on a particular topic through a set of carefully designed sequential questionnaires, interspersed with summarised information and feedback of opinions derived from earlier responses' (Delbecq et al., 1975). Three features characterise the Delphi method in distinguishing it from other group interaction methods: anonymous group interaction and responses; multiple iteration of group responses with interspersed feedback; and the presentation of statistical analysis (Cypher & Gant, 1983; Cochran, 1983; Uhl, 1983; Dailey & Holmberg, 1990; Whitman, 1990). One major aim of the Delphi technique is to explore the extent of consensus about the issues under discussion.
The Delphi technique has four principal advantages felt to be important in gaining the considered opinions of these particular experts:

- it uses group decision-making techniques, involving experts in the field, which have greater validity than those made by an individual (Brooks, 1979);
- the anonymity of participants and the use of questionnaires avoids the problems commonly associated with group interviews: for example, specious persuasion or 'deference to authority, impact of oral facility, reluctance to modify publicised opinions and band-wagon effects' (Martorella, 1991, p.84);
- consensus reached by the group reflects reasoned opinions because the Delphi process forces group members to consider logically the problem under study and to provide written responses (Murry & Hammons, 1995);
- opinions using the Delphi method can be received from a group of experts who may be geographically separated from one another (Murry & Hammons, 1995).

The main disadvantages of a Delphi study are seen as: the length of the process; researcher influence on the responses due to particular question formulation; difficulty in assessing and fully utilising the expertise of the group because they never meet (Murry & Hammons, 1995). The implementation of this Delphi study took full account of the perceived advantages and disadvantages. For example, as science educators, we, (the researchers) have views on the teaching of the processes and practices of science. It is important that these views do not impinge on participants' responses. Therefore, very little guidance was given as to the expected content of responses in the first round of the Delphi study. In the second and third rounds, care was taken to ensure, as far as possible, that participants' own words were returned and they had ample opportunity to comment on our interpretation or conflation of categories of response.

Commonly, the minimum number for a Delphi panel is considered to be ten (Cochran, 1983) with reduction in error and improved reliability with increasing group size. However, Delbecq et al (1975) maintain that few new ideas are generated in a homogeneous group once the size exceeds thirty well-chosen participants. For this study, 23 experts were recruited, with four or five from each category: scientists; science teachers etc. There was no attrition in the group across the three rounds, reflecting the commitment of individuals to the process.

In the first round, participants were asked to respond to three open questions: what they thought school students, by age 16, should be taught about the methods of science; what they thought they should be taught about the nature of scientific knowledge; and what they thought should be taught about the processes and practices of the scientific community. Participants were also requested to state reasons why the 'idea-about-science' was important and the context in which it might be useful. Their open-ended responses to these questions were then analysed and coded reflexively and iteratively to generate a set of 30 themes in the data. Responses were initially grouped, by the second author, according to key terms used by participants, and a summary statement composed reflecting the grouping. This initial analysis was re-examined by the first, fourth and fifth authors to obtain consensus and validation within the research team on the categorisation of the responses. The participants themselves then had opportunity in subsequent rounds to comment on this analysis. For each theme, a summary statement was developed that captured the broad intent of the participants' responses. The themes, and a selection of relevant anonymised arguments for their incorporation, were then fed back to the participants for comment and rating on a 5 point Likert scale in the second round. Using the summed ratings of all the participants then reduced the themes to a subset of eighteen. For the final round, these 18 themes were returned for comment, evaluation and a final rating, together with participants' arguments for their significance.

Emerging outcomes

The first round of the Delphi study elicited extensive comments from most participants. Thirty themes emerged from analysis of the first round responses - each theme having a summary statement, capturing the commonality of responses within that theme. The thirty themes are shown in Table 2.

In the second round of the study participants were asked to comment on each summary - its wording and comprehensiveness, and, particularly, rate on a five point scale the importance of the intent behind the theme and its summary for inclusion in the school science curriculum, justifying their rating. Each summary was accompanied by some anonymised comments from the first round, which exemplified the range of comments coded under that theme. Participants were encouraged to make comments on the statements supporting the theme. They were also asked whether any themes should be merged. The ratings for each of these thirty themes are shown in table 2.

For the third round, the number of themes under consideration was reduced. This was done for two reasons - thirty themes were considered too many for the second phase of the research, working with teachers in developing pupils' understanding; reducing the number forced the participants to argue more specifically for inclusion of particular ideas. The top rated themes were used for round 3 on the basis of a suitable cut-off point from the ratings and manageability of the total number of final themes. Theme summaries were returned to participants along with exemplification of comments on that theme from round 2. The summaries of some themes were merged and/or modified as a result of participants' comments in the second round, with the resultant split of one theme - giving 18 in total. Participants were asked to rate each theme again on the premise that it should be *explicitly* taught, justifying their rating. They were also asked to comment on the wording of the summary, the completeness and comprehensiveness of all themes and their experience of the Delphi process.

The details of one of the themes emerging from round 1, with its representation for round 2, including typical statements, are shown in Figure 1. Beneath in Figure 2 is shown the representation for the same theme for round 3 with participants' comments on the ranking.

The themes for round 3 with their ratings are shown in table 3. Comparison of the ratings in rounds 2 & 3 (tables 2 & 3) shows a stability in opinions across the second two rounds, the only major exception being where a category was split between the two rounds. *Features of scientific knowledge* was split into *Status* and *Characteristics*. The *characteristics of scientific knowledge* were seen as more important by participants.

Table 2 Themes for round 2 of the Delphi study, including the ratings given in round 2 (Themes are in the order resulting from Round 2)

Theme title	Mean	Mode	S.D.
Experimental methods and critical testing	4.4	5	0.7
Tentative nature of scientific knowledge	4.3	5	1.0
Diversity of scientific method	4.0	4	1.1
Hypothesis and prediction	4.0	5	1.1
Historical development of scientific knowledge	4.0	4	1.0
Creativity	4.0	5	1.1
Science and questioning	4.0	5	1.3
Observation and measurement	3.9	5	1.0
Analysis and interpretation of data	4.1	5	1.3
Specific methods of science	3.9	4	1.1
Moral and ethical dimensions in development of scientific knowledge	3.9	5	1.3
Types of knowledge	3.7	4	1.1
Features of scientific knowledge	3.7	4	1.4
Cumulative and revisionary nature of scientific knowledge	3.9	4	1.0
Science and technology	3.7	4	0.9
Cooperation and collaboration in development of scientific knowledge	3.6	5	1.5
Cause and correlation	3.7	5	1.4
Common conceptions of science and risk	3.6	3	1.3
Developments in scientific knowledge are subject to peer review	3.6	4	1.3
Contextual nature of science	3.3	3	1.2
The language of science	3.3	3	1.0
Science as a human, collaborative activity	3.3	4	1.0
Reporting scientific findings	3.2	4	1.3
Constraints on the development of scientific knowledge	3.0	3	1.0
Scientific knowledge and values	2.9	3	1.5
Role of ICT	2.8	2	1.5
Range of fields in which scientific knowledge is developed	2.7	4	1.2
Distinction between science and technology	2.3	3	1.4
Accountability and regulation of scientific practices	2.3	2	0.9
No general ideas independent of science content	2.2	1	1.5

Figure 1 Detail of one theme for round 2 - nature of scientific knowledge

Round 2

The tentative nature of scientific knowledge

Summary

Pupils should recognise that scientific knowledge is provisional. Current scientific knowledge is the best we have but may be subject to further change given new evidence.

Typical statements

(a) Scientific knowledge is in a state of continuous change. Theories are the best we can do with the current state of knowledge.

(c) Theories can be falsified if wrong; they can be modified and extended if correct only in a limited region.

(d) That scientific knowledge is not fixed for all time because scientific ideas are adapted and revised in the light of new evidence.

(g) That scientific knowledge is tentative. Scientific knowledge depends on the available evidence and methods for gathering it. As technology makes more precision possible, so new evidence may be revealed, so ideas change. We should always regard scientific knowledge as the best we know at the moment and subject to change.

(i) They should be taught that scientific knowledge is the best kind of knowledge we have when it comes to understanding the natural world, but this does not make it perfect. They should understand that you have to get by with the best even if it is not perfect and often this will be scientific knowledge.

Figure 2 Detail of one theme for round 3 - nature of scientific knowledge

Round 3

Science and Certainty

Summary

Pupils 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 also 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.

Typical comments in support

(a) It is not simply a matter of 'new evidence'. It is sometimes a matter of new perspectives. I would wish to stress this. Think not only of Galileo, Newton and Darwin, but of countless others (Fleming) in science and technology who have made progress by re-conceptualising a problem or even identifying the problem in the first place. I would want to find room for the incompleteness of scientific knowledge. The DNA structure is only part of the genetic code. We still do not know how proteins fold!

(b) Scientific knowledge is provisional <u>not</u> because it goes beyond the 'facts', but because the 'facts' will change and go beyond the science!

(c) Arguably the most essential of all, from the conceptual standpoint and public policy standpoint, provided it is linked well with Theme 1 (The Empirical Base of Scientific Knowledge) and Theme 2 (The Status of Scientific Knowledge and The Characteristics of Scientific Knowledge)

Table 3 Round 3 Themes and their ratings

Theme Title and summary	mean	mode	S.D
Creativity Pupils 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.	4.4	5	0.7
Experimental method and critical testing Pupils 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.	4.4	5	0.8
Diversity of scientific thinking Pupils should be taught that science uses a range of methods and approaches and that there is no one scientific method or approach	4.2	4	0.7
Science and questioning Pupils 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.	4.2	4	0.7
Cooperation and collaboration in the development of scientific knowledge Pupils 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.	4.2	5	0.8
Historical development of scientific knowledge Pupils should be taught some of the historical background to the development of scientific knowledge.	4.2	5	0.9
Science and certainty Pupils 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	4.2	4	0.9
Analysis and interpretation of data Pupils 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.	4.2	5	0.9
Hypothesis and prediction Pupils should be taught that scientists develop hypotheses and predictions about natural phenomena. This process is essential to the development of new knowledge claims.	4.2	5	1.0
Moral and ethical dimensions in the development of scientific knowledge Pupils should appreciate that choices about the application of scientific and technical knowledge are not value free; they may, therefore, conflict with moral and ethical values held by groups within society.	4.1	5	1.0
Observation and measurement Pupils should be taught that observation and measurement are core activities of scientists; most measurements are subject to some uncertainty but there may be ways of increasing our confidence in a measurement.	4.0	5	0.8
Science and technology Pupils should be taught that, whilst there is a distinction between science and technology, the two are increasingly interdependent as new scientific discoveries are reliant on new technology and new science enables new technology.	3.8	4	0.8

Table 3 Continued

Theme Title and summary	mean	mode	S.D
Specific methods of science Pupils should be taught a range of techniques for data representation and analysis commonly used in the sciences, with particular emphasis on those necessary for interpreting reports about science, particularly those in the media.	3.8	4	1.1
The Characteristics of scientific knowledge (Features of scientific knowledge) Scientific knowledge aims to be general and universal. Scientific explanations are based on models and representations of reality which are often simplifications of the complexity of the real world. Scientific knowledge may also, in some instances, appear to be counter-intuitive.	3.7	3	0.9
Cause and correlation Pupils should be taught to distinguish two types of relationship in science ñ causal, where there is a known mechanism relating an effect to a cause; and correlational, where identified variables are associated statistically but for which there is no well-established causal link.	3.7	3	1.1
The empirical base of scientific knowledge (Types of knowledge) Pupils should be taught that a distinctive characteristic of scientific knowledge is that it is supported by empirical evidence. Whilst the evidence for some ideas is well-established, other knowledge is less secure as the empirical base is less reliable.	3.6	4	0.9
Cumulative and revisionary nature of scientific knowledge Pupils should be taught that much scientific knowledge is cumulative, building on that which is already known. . New theories and methods are often resisted but ultimately may be accepted if they are seen to have better explanatory power, parsimony or elegance.	3.6	5	1.3
The Status of scientific knowledge (Features of scientific knowledge) Pupils should be taught that science produces reliable knowledge of the natural world that can be relied upon as a basis for action.	2.8	3	1.2

Most of these themes are highly rated overall, suggesting a *broad consensus* within the group as to the important elements of 'ideas-about-science' which should be included in the science curriculum. This does not mean there was *unanimity* from experts within each theme or overall, however. Individuals, within the expert group, have their own strong and, to a greater or lesser extent, different perspectives on the nature of science as evidenced by their detailed comments on the themes.

An extreme example of the difference in opinion is shown by contrasting comments about *the status of scientific knowledge*, the theme with the least support:
SE02 *'No! It cannot always be relied upon as a basis for action. Examples abound e.g. the Cumbrian/Chernobyl issue, pesticide contamination, BSE and countless others. Once science is in the world of action, many unforeseen problems arise.'*
S07 '*This is the reason for teaching science in schools.'*

Another response within this theme illustrates that participants recognised some underlying differences of opinion about the nature of science and highlights the difficulty in interpreting summary statements:
PS03 *'It all depends what you mean by 'science'. But in theme 8 and 1 are the assertions that not all 'scientific knowledge' is well attested so I take it that it cannot be relied upon'.*

Nonetheless, from this diversity of views about the nature of science emerged themes with support from the vast majority of participants (Table 3). The Delphi technique proved helpful in allowing all ideas to be given consideration in a systematic and reflective way - a process which may have proved more problematic using group interviews.

These themes have a reasonably close relationship to the analysis of international science education standards documents conducted by McComas and Olson (1998). In exploring eight science curriculum blueprints they categorised statements of the nature of science under the four broad headings of: Philosophical, sociological, psychological and historical insights, statements and assumptions. Like the participants in the Delphi study, they indicate the interrelation of some of the discrete statements. They found that the common elements to all the components which fell under the broad heading of *nature of science* was the following set of statements emerging from philosophy, sociology, psychology and the history of science (McComas et al, 1998 p6):

- Scientific knowledge while durable, has a tentative character
- Scientific knowledge relies heavily, but not entirely, on observation experimental evidence, rational arguments, and scepticism
- There is no one way to do science (therefore there is no universal step-by-step scientific method
- Science is an attempt to explain natural phenomena
- Laws and theories serve different roles in science, therefore students should note that theories do not become laws even with additional evidence
- People from all cultures contribute to science
- New knowledge must be reported clearly and openly
- Scientists require accurate record keeping, peer review and replicability
- Observations are theory-laden
- Scientists are creative
- The history of science reveals both an evolutionary and a revolutionary character
- Science is part of social and cultural traditions
- Science and technology impact on each other
- Scientific ideas are affected by their social and cultural milieu

Whilst the headings may be different, they are essentially describing many similar features found through this Delphi study. McComas and Olson's analysis, taken together with this work, would support the view that there is an emerging consensus about the basic features and ideas about science that should be taught to school students. A difference between the two studies is that the Delphi study is supported by reasoned arguments by the expert group whereas the basis for inclusion of particular statements and their meaning was not always clear in international science education standards documents.

Over the decades, science has gradually evolved a sense of what a simplified or, to use the rather effective French term, a 'vulgarised' treatment of most of the core science topics looks like. We make no pretence that the account we first give learners of the structure of atoms and molecules, or of the behaviour of electric circuits, or of the components of a cell, reflects the current scientific understanding. They are simplified accounts, which can provide a basis for later learning of more sophisticated models and ideas. But parallel conceptions of what a vulgarised epistemology of science would be like are not so well-established. We feel that this work has made a significant contribution to establishing that account and evidence on which to base the practice and teaching of 'ideas-about-science'.

We intend to carry out further analysis of the detailed comments on the statements, summaries and themes, with a view to translating the themes into a basis for teaching ideas-about-science, for which there is broad expert consensus. This analysis will re-examine the wording of themes, according to the nature of comments and consider their representation in the existing school science curriculum.

Collaboration with teachers

In the second phase of the project the outcomes of the Delphi study, together with other evidence and views from the research and development literature, will inform the design of sets of activities for the 'implemented' curriculum to support the teaching of 'ideas-about-science'. The work will be undertaken in collaboration with a group of teachers, four from each of KS2, KS3 and KS4.

In this phase, the participating teachers from each Key Stage will use these activities over a period of two school terms with the same class. The outcomes will be evaluated using a combination of methods - teacher diaries; pupils' evaluation of lesson aims and outcomes, both cognitive and affective; video evidence for analysis of the types of activities promoted. In addition pre- and post-tests will be developed to measure pupils' understanding of 'ideas-about-science' and results will be compared with data from similar groups of pupils who have not experienced these lessons. This stage will draw on the diagnostic methods and assessment expertise developed in project 1. The classroom-based observations and teachers' reflective diaries will provide another data set of the evidence that teachers draw on in evaluating innovative approaches.

Several obstacles stand in the way of success, as Langer and Applebee (1987) point out

'We are unlikely to make fundamental changes in instruction simply by changing curricula and activities without attention to the purpose the activities serve for the teacher as well as for the student. It may be much more important to give teachers new frameworks for understanding, what to count as learning than it is to give them new activities or curricula.........To summarise bluntly, given traditional notions of instruction, it may be impossible to implement successfully the approaches we have championed.'

We hope, therefore, that this work will, when publicised more widely, offer teachers a new, more empirically based framework for the content of the curricula they may be asked to enact. Given, too, the relative paucity of work or materials that support the teaching of 'ideas-about-science', we hope that the second phase of the research will contribute to the development of a larger body of tried and tested materials from which teachers can draw, particularly for the new 'Ideas and Evidence' component of the science National Curriculum. In addition, this phase of the research work will enable us to develop a better understanding of some of the problems of teaching about the nature of science to pupils of a wide variety of ages.

In a review of science teachers' awareness of the findings from research, Costa et al (2000) found that even science teachers wishing to extend and develop their practice showed a lack of awareness of the outcomes of science education research. Yet, of all the disciplines, it would be not unreasonable to expect science teachers (whose discipline holds a core commitment to evidence as a means of knowledge generation) to at least take cognisance of the evidence emerging from research. This project will both contribute to that empirical base, and explore how the relationship between research and the practitioner can be improved.

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Harbo's doctoral research findings on Social pedagogical perspectives on fidelity to a manual: Professional principles and dilemmas in everyday expertise 1.Â The main objective of this work was to develop and implement an evidence-based education programme aimed at enhancing roller-hockey coachesâ€™ coaching effectiveness to optimize playersâ€™ psychosocial development.Â the coaches, (c) development of an education program with the objective of teaching coaches how to promote the 5Cs (i.e., commitment, communication, concentration, control, and confidence) of the playersâ€™ psychosocial development, (d) assessment of the program, and (e) monitoring of the programâ€™s effects through the time.Â Evidence-based practice in school mental health. 4 Research Network: Evidence-based Practice in Science Education (EPSE) Professor Robin Millar (York) (Co-ordinator) Professor John Leach (Leeds) Professor Jonathan Osborne (Kingâ€™s College London) Professor Mary Ratcliffe (Southampton).Â Interviews Perceptions of: the nature of research in science education the influence of research on current practice any contribution of research to improving and evaluating practice.Â 20 Towards evidence-based practice Research culture â€“ supporting and enhancing professional networks Research tools â€“ providing teachers with understanding of social science research processes and diagnostic tools Translation of convincing research findings into practical strategies that â€˜fitâ€™ with professional experience. The evidence-based STEM education research is described and placed in the STEM teacher education context. The paper shows how this research may help reverse the growing student STEM disengagement, support effective learning environments, bring attention to teacher professional development, and inform STEM education policy.Â This approach emphasizes teacher-candidates' active engagement with research-based pedagogies as learners and as future teachers. It provides a universal framework for incorporating research-based pedagogies in teacher education as described in the two examples. The first example showcases Peer Instruction