Epistemological perspectives in research on teaching and learning science

John Leach

Centre for Studies in Science and Mathematics Education
The University of Leeds
Leeds LS2 9JT
UK
j.t.leach@education.leeds.ac.uk

Paper presented as part of the symposium *Research on epistemology: bridging disciplinary boundaries and theoretical perspectives*, American Educational Research Association, San Francisco, April 2006.

Presenters were asked to address three issues:

1) What is the *scope* of epistemological knowledge?
2) What kind of knowledge is epistemological knowledge?
3) Instruction in epistemology.

This paper is presented in response.

WORK IN PROGRESS: PLEASE CONTACT THE AUTHOR BEFORE CITATION

Epistemological perspectives in research on teaching and learning science

John Leach

THE SCOPE OF THE PAPER

This paper is concerned with epistemology – the branch of philosophy that addresses the warranting of knowledge claims – as it relates to research on teaching and learning science. The paper presents an overview of different areas of work in science education which make explicit reference to epistemology, making particular reference to studies of students' and teachers' perspectives on learning, and on public scientific knowledge. Given the size of the literature, no attempt has been made to make a comprehensive review. Rather, a small number of studies are used to illustrate the scope of epistemological perspectives as they inform research on teaching and learning science.

The paper goes on to identify claims that appear well-established from the research. Authors' assumptions about the nature of epistemological knowledge[1] as relevant to teaching and learning science are discussed, as are the implications of findings and perspectives for teaching epistemological knowledge in science education.

EPISTEMOLOGY AND SCIENCE EDUCATION

Research scientists are professional epistemologists: they are paid to generate knowledge that has been warranted through explicit processes as reliable. Within fields of enquiry, there are established norms for warranting knowledge claims as reliable, which typically have both empirical and institutional dimensions. A relatively small percentage of those who use science are employed to generate new knowledge, however: the majority are involved in using established knowledge to generate outcomes of some kind or another,

[1] The phrase 'epistemological knowledge' is used very broadly in this paper to include public knowledge claims in the science studies literature, as well as epistemological beliefs that appear to be used by individuals in particular situations. The use of the word 'knowledge' should not be construed as suggesting formal warranting. I address this issue at the end of the paper.

whether as employees undertaking routine work such as processing laboratory samples or as members of the public involved in environmental activism. In most situations the person using scientific knowledge has to make strategic decisions about which pieces of scientific knowledge it is appropriate to use, the extent to which that knowledge has been shown to be reliable, and the boundary conditions of that knowledge. These decisions all require epistemological knowledge, even though that knowledge may well be tacit.

Academic work in science education has addressed how students can be equipped to deal with epistemological aspects of the generation and use of scientific knowledge. The literature contains a significant number of papers which address students' and teachers' epistemological perspectives on public scientific knowledge. How do people – particularly science learners and science teachers – become able to deal with epistemological aspects of science? It could be that this is a skill that people 'just pick up' as they are exposed to science either through formal instruction or through living in a society where science and technology are prominent. Studies of the epistemological knowledge used by science learners and science teachers suggest that some of what is 'just picked up' about epistemology as a result of science education and experience of living in the world is not defensible. This is because the epistemological knowledge used results in difficulties in learning new conceptual content, or results in people using scientific knowledge inappropriately in a given situation.

There has also been a good deal of writing which addresses the epistemological assumptions held by educational researchers about public scientific knowledge and science learning, and how these assumptions have influenced research on teaching and learning as well as scholarly perspectives about the curriculum. Drawing upon insights from the history, philosophy and sociology of science, proposals have been made about epistemological content that should be included in the science curriculum, and how that content might best be taught.

In addition, science educators have drawn upon work conducted on students' views of learning, as this is potentially relevant to how students approach learning tasks in their science education.

Figure 1 summarises these areas of work:

	Perspectives on the nature and generation of public scientific knowledge	*Perspectives on learning (i.e. the nature and generation of personal knowledge)*
Students' and teachers' perspectives	Students' and teachers' views of the nature and generation of public scientific knowledge, and perspectives on teaching about the nature and generation of public scientific knowledge	Students' and teachers' views of the nature of learning
Researchers' perspectives	Researchers' views of the nature and generation of public scientific knowledge, and implications for studies of learning and curriculum	Researchers' views of the nature and generation of personal knowledge; implications for studies of learning and curriculum proposals

Figure 1: Epistemological foci in scholarly work in science education

This paper considers each of these four areas of work. Students' and teachers' perspectives are presented in more detail, reflecting the relative emphasis that has been made in the research literature. Each section addresses the range of methodologies used, the claims that have been advanced about epistemological knowledge, the validity of those claims, the implications for practice, and the future research agenda. Scholarly writing often addresses researchers' perspectives on both public scientific knowledge and on learning; these issues are therefore addressed within one section of this paper.

EMPIRICAL STUDIES OF STUDENTS' AND TEACHERS' EPISTEMOLOGICAL PERSPECTIVES ON PUBLIC SCIENTIFIC KNOWLEDGE

There is now a vast research literature reporting empirical studies of students' epistemological perspectives on public scientific knowledge. Lederman (1992), Driver, Leach, Millar and Scott (1996) and Désautels and Larochelle (1998) have reviewed this literature, and Bell, Abd-El-Khalik, Lederman, McComas and Matthews (2001) have published a bibliography of studies. Studies have addressed different aspects of students' epistemological perspectives on public scientific knowledge. These include the purposes of scientific activity and the demarcation of science as a domain, the nature and status of scientific knowledge and its relationship to empirical evidence, and social and institutional aspects of the scientific enterprise. A range of methods of study have been used (Leach, 1996), and studies have been underpinned by different epistemological assumptions on the part of investigators.

The methodology and framing of studies of students' and teachers' epistemological perspectives on public scientific knowledge

There is considerable variation in the methods used for framing investigations of students' epistemological perspectives on public scientific knowledge. Some studies appear to be designed on the assumption that it is possible to identify a 'target' epistemological perspective that is superior to others. Students holding this perspective would therefore be judged as holding a more sophisticated epistemology than their peers. The design of such studies involves eliciting students' views about science in general, rather than particular contexts in science. The 'target' epistemological perspective is used as a norm against which students' views are compared in analysis. Examples of studies based on assumptions such as these include the work of Halloun and Hestanes (1998) and Songer and Linn (1991), reported later in this paper.

No single epistemological perspective is supported by historians, philosophers and sociologists of science, and by scientists. It is therefore problematic to identify one epistemological perspective on public scientific knowledge that is uniquely superior to others, and that should therefore be taught to science students. However, there is evidence that experts agree, at a fundamental level, that some core epistemological perspectives are sufficiently applicable across a range of contexts to be taught through the school curriculum (e.g. McComas and Olson, 1998; Osborne, Collins, Ratcliffe, Millar

and Duschl, 2003, reported later in this paper). It is legitimate to investigate the extent to which students share these core epistemological perspectives by analysing data on students' views against a specified normative perspective.

A case has been made that understanding science involves understanding the relative status and security of knowledge claims within the scientific community (Duschl, 1990). Studies have been designed with the assumption that different epistemological perspectives are legitimate in different contexts, and that students' epistemological perspectives are likely to be influenced by context. The design of such studies involves eliciting students' views in a range of specific contexts, and analysing data ideographically, rather than against a predetermined norm. This methodology allows for inferences about the range of contexts across which students are likely to draw upon particular epistemological perspectives. Examples of studies based on assumptions such as these include Driver, Leach, Millar and Scott (1996), Leach, Millar, Ryder and Séré (2000) and Brickhouse, Dagher, Shipman and Letts (2000). The knowledge generated from studies such as these is suitable for informing teaching in specific contexts.

Studies have been conducted which assess the epistemological perspectives that students espouse in response to direct questions. The work of Songer and Linn (1991), reported later in this paper, is an example of this approach. Other studies investigate the implicit epistemological perspectives that appear to influence students as they undertake some kind of task, be it a task designed as part of a survey (e.g. Aikenhead, Fleming and Ryan, 1987; Driver et al., 1996; Leach et al., 2000), or an authentic classroom activity (e.g. Lewis, 2002; Ryder, 2002; Séré and Guillon, 2002). The epistemological perspectives espoused by both students and professional scientists may not be the same as the perspectives that inform their action (Rowell and Dawson, 1983; Samarapungavan, 1992). It does not, therefore, appear legitimate to draw conclusions about the epistemological perspectives that inform students' (or teachers', or scientists') actions based upon studies of their espoused knowledge alone.

There have been several attempts to produce reliable and valid written test instruments to assess students' epistemological perspectives (e.g. Halloun and Hestanes, 1998). Recent work has questioned the extent to which the complex, mulitifaceted nature of students' epistemological perspectives can be captured through pencil-and-paper instruments, as

opposed to more interactive methods such as interviews (Kelly, Chen and Crawford, 1998; Lederman, Wade and Bell, 1998; Leach et al., 2000). However, although interviews improve the probability of producing valid knowledge about students' epistemologies, they are time-consuming to conduct and analyse. Furthermore, if science curricula are to be developed which place more emphasis upon students' epistemological understanding of the generation and validation of reliable public knowledge it will be necessary to develop valid, reliable written assessment items that can be administered on a large scale. The *Views Of the Nature of Science* (VNOS) instrument (Lederman, Abd-El-Khalik, Bell and Schwartz, 2002) was developed for this purpose, and has been used by the originators and other researchers to collect evidence about science students' responses to questions about the nature of science such as:

> *After scientists have developed a theory (e.g. the atomic theory), does that theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.*
>
> (p. 505)

The questions are open-ended, and probe students' explicit statements about the nature of science, contextualized in examples of the student's choice. The authors present evidence that the VNOS instrument produces a valid and reliable assessment of students' explicit epistemological knowledge, with some reference to examples.

Findings from surveys of students' and teachers' epistemological perspectives on public scientific knowledge

Studies have been reported which address the epistemological perspectives on scientific knowledge used by students from primary school to university age. Given the diversity of methods used, findings are surprisingly similar. Key findings from this work will be presented, and their significance discussed.

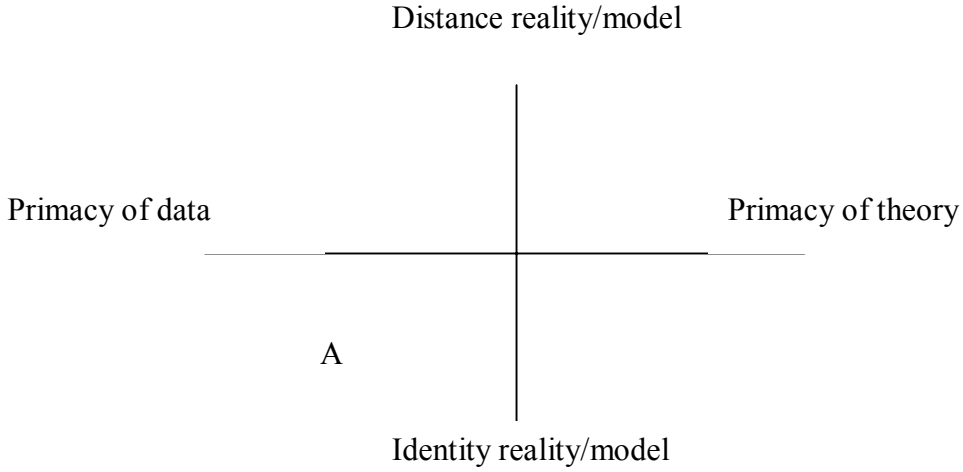
Perhaps the most significant point to emerge from the research is that students do indeed develop epistemological perspectives on public scientific knowledge as a result of their interactions with science in school and society. However, rather than developing coherent epistemological perspectives, students' epistemological knowledge tends to be implicit and context-specific (Désautels and Larochelle, 1998). This is not surprising,

given that explicit teaching about epistemological issues is given very little time in most science curricula.

In their review of studies of students' epistemological perspectives on public scientific knowledge, Désautels and Larochelle (1998) suggest that

> *'...students tend to impart meaning to the 'relational world' of scientific knowledge by transposing the latter into the world of everyday materiality, by 'thingifying' this knowledge in a certain way…'*
>
> p. 115

In other words, many students do not appear to recognise an ontological distinction between the observable objects and events of the material world, and the entities (*gene*, *bond*, *point mass*) that are created and defined for the purpose of building scientific knowledge. In reviewing the responses of high school and university students to questions about specific laboratory investigations, Séré, Fernandez-Gonzalez, Gallegos, Gonzalez-Garcia, De Manuel, Perales and Leach (2001) propose a framework for considering the ontological and epistemological features of the students' responses. Individual responses are categorized across two axes, according to the relative primacy of theory and data, and the correspondence or distance between objects and events in the world and the models used in science to explain those objects and events:



(p.505)

Responses in position A of the quadrant are data-focused, and do not appear to differentiate reality from models used in science to describe and predict. For example, when presented with sets of measurements many students argued that each result should be treated in its own terms as each is of equal value. Such students did not appear to recognize how sets of measurements can be treated *as a set*, and used as a body of evidence against which claims can be evaluated.

This lack of recognition of the ontological distinction between objects in scientific explanations and objects in the material world has far-reaching implications for students' learning of public scientific knowledge. There is evidence that students who do not make an explicit distinction between observable or taken-for-granted entities, and the entities of scientific knowledge, misinterpret the purpose of scientific investigation. Driver, Leach, Millar and Scott (1996) illustrated this phenomenon by presenting pairs of students, aged 9, 12 and 16, with short descriptions of activities, some of which involved empirical investigation. One activity described a simple test in which a balloon was stretched over the neck of a bottle. When the bottle is heated, the balloon inflates. A simple test was then carried out in which the apparatus is heated with the balloon at the top, and then at the bottom, in order to find out whether the inflation of the balloon is due to hot air *rising* or *expanding*. The purpose of the test was portrayed to students as testing a relationship between a model of the behaviour of air, and the inflation of a balloon. However, significant numbers of students at all ages re-interpreted the activity as a test of *the relationship of the orientation of the bottle to the inflation of the balloon*, recasting the test in terms of *observable* features of the material world.

This tendency does not appear to be restricted to young learners. In a case study of a 21-year-old university student working on an open-ended investigative project in physical chemistry, Ryder and Leach (1999) demonstrated that, throughout the project, the student saw the purpose of her work as collecting and displaying data. This was in conflict with her supervisor's view that the purpose of the project was to evaluate different models of non-linear reaction kinetics. Another example comes from the work of Marie-Geneviève Séré and her associates (Séré, 1993; Séré et al., 2002), focusing upon the ways in which university students handle measured data in physics. Depending upon the context, many students assume that a 'true' value for a quantity is best determined from a data set by

taking the most frequently occurring repeat measure (the mode). This view suggests that students do not recognise that the process of measurement in many contexts in physics is based upon modelling, and prone to errors. Rather, they assume that measurement involves a simple correspondence between the value recorded on an instrument, and the behaviour of the material world.

Several studies illustrate that, because students appear not to draw any ontological distinction between the entities from which much scientific knowledge is built and objects in the material world, they assume that scientific knowledge can be warranted through simple empirical tests (e.g. Fleming, 1987; Driver et al., 1996; Larochelle and Désautels, 1989; Désautels and Larochelle, 1999). In other words, 'proving' a claim is a simple matter of collecting enough data of the right quality, and analysing it logically. Such students do not appear to recognise steps in the process of building scientific knowledge that are *under-determined* by data. Such steps might involve, for example, the creation of new entities ('gene') that do not emerge directly from data, or the construction of models. Furthermore, the only possible reason for disagreement between scientists is seen as being due to incompetence or bias, because 'the facts speak for themselves'. This is particularly significant when students encounter information about scientific issues where there are differences of opinion. For example, Driver et al. (1996) showed that many 16-year-old students thought that the safety or otherwise of irradiation as a method of food preservation could be proved by simple empirical tests. In general, students appear unfamiliar with the social and institutional processes through which scientific knowledge is warranted as reliable (Désautels and Larochelle, 1998).

There is some evidence that older science students use an extreme relativist perspective when they recognise that scientific knowledge is underdetermined by data, assuming that no knowledge claim can ever by judged as better or worse than another (Ryder and Leach, 2000).

A small number of studies have been conducted which suggest that students use sometimes radically different epistemological perspectives when discussing different aspects of science. It would not, of course, be desirable for students to adopt a single epistemological perspective to explain all the situations that they encounter in science. The empirical processes for warranting knowledge as reliable are very different in

disciplines such as astrophysics, paleontology and epidemiology, and some knowledge claims are much better established than others. However, rather than drawing upon a profile of epistemological knowledge about the generation and validation of scientific knowledge claims in a logically consistent way, there is evidence that many advanced science students make inconsistent epistemological statements about similar situations, and that their statements are erroneous or naïve (e.g. Leach et al., 2000; Brickhouse, Dagher, Shipman and Letts, 2000; Roth and Roychoudrey, 1994; Sandoval and Morrison, 2003).

There is no consensus within the literature about the teaching approaches that might be used to promote more sophisticated epistemological perspectives on public scientific knowledge amongst students. Some advocate explicit teaching about the history and philosophy of science (e.g. Matthews, 1994; Matthews, 1997), on the grounds that a systematic introduction is the only way to open up complex epistemological issues with students. Others advocate an approach whereby epistemological ideas are made transparent in contexts encountered by students during normal teaching (e.g. Driver et al., 1994; Tiberghien and Megalakaki, 1995; Leach et al., 2000; Séré and Guillon, 2002), or an intermediate approach (Galili and Hazan, 2001), or through explicit teaching about scientific argumentation (e.g. Kuhn, 1991; Driver, Newton and Osborne, 2000). The advantage of addressing epistemological issues in context, it is argued, is that students can be introduced to epistemological perspectives in the context in which such perspectives are likely to be used (Leach, 1996; Ryder, Leach and Driver, 1999; Leach, Hind and Ryder, 2003).

A further strand in the literature addresses teachers' epistemological understanding in science, and the influence of that knowledge on teaching (Brickhouse, 1990; Hodson, 1993). Although there is some evidence that many high school science teachers' responses to questionnaire items about the nature of science are naïve in similar ways to many students' responses (e.g. Lakin and Wellington, 1994; Bandiera et al., 1998; Lederman, 1992), there is conflicting evidence about the extent to which this influences their teaching. For example, although Brickhouse (1990) demonstrates a link between teachers' epistemological commitments and the messages about science communicated through their teaching, Hodson (1993) suggests that teachers' epistemological commitments are relatively unimportant in shaping their teachers, compared to other,

more pressing everyday constraints. There is still relatively little evidence about the relationship between teachers' espoused epistemological knowledge about public scientific knowledge and their classroom teaching practice.

Links between students' epistemological perspectives on public scientific knowledge and their learning of science

Several approaches can be identified which focus on the significance of students' epistemological perspectives on public scientific knowledge in specific contexts associated with their learning. Some studies have been reported in the literature, which draw correlations between students' epistemological perspectives on public scientific knowledge and their performance on content understanding. Halloun and Hestenes (1998) report a study in which North American high school and university students' epistemological perspectives on public scientific knowledge and learning were correlated with their performance in physics. The Views About Science Survey (VASS) was used to characterise what Halloun and Hestenes term 'student views about knowing and learning physics' (p. 553). This instrument consists of 30 items, 13 of which relate to students' epistemological perspectives on public scientific knowledge. Each item presents students with a pair of polarised statements, and students are required to rate their viewpoint between the positions on an 8-point scale. Although the authors recognise that it is sometimes legitimate to use different epistemological perspectives according to the context, the pairs of statements nonetheless refer to science in general, rather than specific contexts. Students' views are then characterised as Expert, Mixed and Folk. 'Expert' views of public scientific knowledge portray it as a coherent body of knowledge that is refutable (rather than a loose collection of directly perceived facts).

A positive correlation between Expert views of knowing and learning physics and students' performance on physics learning is demonstrated, and the authors claim that this is evidence that 'student views about knowing and learning physics may be major determinants of achievement in physics courses' (p.575). This claim is certainly plausible, and the authors are commendably cautious not to over-interpret the data available from the VASS. However, it is not possible to attribute a *causal* relationship on the basis of a correlation such as this one. If an 'Expert' profile on the VASS caused improvements in physics content learning, an obvious implication for instruction would

be to teach towards an Expert profile. However, there is an equally plausible interpretation of the correlation. Learning physics content can legitimately be viewed as having an epistemological dimension. Part of understanding Newtonian mechanics or thermodynamics is understanding how to use this knowledge to explain phenomena in the material world. Students who 'understand' such content would therefore be expected to score highly on both content and epistemological tests. Alternatively, another possibility is that one would expect a correlation between students' performance on a test of physics content knowledge, and their performance on another intellectually demanding activity such as the VASS.

There is evidence that what students *say* on surveys, and what they *do* in learning situations, are not the same (Rowell and Dawson, 1983). There are some examples of work which, rather than investigating possible correlations between students' scores on content and epistemological test items, address the epistemological basis of student learning in specific learning domains. Examples of such studies include a series addressing elementary thermodynamics (Tiberghien and Megalakaki, 1995; Tiberghien, 1996; Tiberghien, 2000), chemistry (Le Maréchal, 1998), genetics (Cartier and Stewart, 2000; Lewis, 2002), biochemistry (Leach, 2002b), geology (Ryder, 2002), labwork (Leach et al., 2000; Ryder and Leach, 1999; 2000; Séré, De Manuel, Fernandez-Gonzalez, Gallegos, Gonzalez-Garcia, Leach and Perales, 2001; Leach, 2002a; Guillon and Séré, 2002) and particle theory (Vollerbreght, 1998). The methodology used by Andrée Tiberghien and her associates can be used as illustrative of one approach in this area. Tiberghien's work portrays students' learning in physics as a process of *modelling*, in which students develop explicit links between a world of theories and models, and a world of phenomena an events, via models (Tiberghien, 2000). Teaching activities are designed to encourage students to make particular links, and the extent to which those links are made is evaluated through assessment items (which are built into the teaching sequence). This methodological approach makes explicit both content and epistemological goals for the instruction, and evaluates the extent to which those goals are achieved.

A radically different approach to developing students' epistemological knowledge in science involves constructing learning environments which share key features of authentic research environments. Various examples of such work for school and

university students have been described in the literature (e.g. Roth, 1995; Roth and Bowen, 1999; Ryder and Leach, 1999). The approach involves constructing a science curriculum which requires students to participate in knowledge-generating activities, and by doing this, students learn key features of the process of knowledge generation. Evidence is presented to suggest that students learn a good deal about the epistemic practices of science through such experiences – though, of course, there are practical difficulties in constructing science teaching of this kind on a large scale.

There is still rather limited evidence about the effectiveness of these various approaches to developing students' epistemological knowledge through science education. Future work might usefully focus upon the design, implementation and evaluation of teaching approaches that are realisable in the context of various different national education systems, which aim to promote both conceptual and epistemological understanding amongst students.

EMPIRICAL STUDIES OF STUDENTS' EPISTEMOLOGICAL PERSPECTIVES ON LEARNING

The literature contains reports of studies where school and university students answer questions about the nature of their own learning. In some cases, studies focus specifically upon *science students'* views about their own learning. Such studies appear to be based on the premise that a student's view of the nature of the knowledge being studied, and purposes of learning, will influence their goals and actions during study and thereby influence the success of their learning.

The approach used can be illustrated by reference to a study carried out by Schommer, Crouse and Rhodes (1992). In this study, a group of 424 North American university students completed a questionnaire which was used to characterise their views of both *knowledge* and *learning*. They had to rate their agreement or disagreement with statements about learning on a 5-point scale. The authors quote the following items as illustrative of others on the questionnaire:

Dimension under investigation	*Statement against which students have to rank their opinion*
Knowledge is certain	1 Scientists can ultimately get to the truth
Success (in learning) is unrelated to hard work	2 The really smart students don't have to work hard to do well in school
Avoid ambiguity	3 I don't like movies that don't have an ending
Learning is quick	4 Successful students learn things quickly

The authors then use a factor analysis of students' responses to characterise their views of knowledge and learning. Beliefs in externally controlled learning, quick learning, simple knowledge and certain knowledge were identified from the factor analysis. The authors imply that this view of knowledge and learning is incorrect, in that individuals do have control over their learning, learning is a gradual process involving effort, knowledge is best characterised as networks of related ideas, and knowledge is tentative.

The students then completed a reading comprehension task on a passage about statistics. The authors found a negative correlation between an incorrect view of knowledge and learning, and comprehension of the passage.

Fundamental criticisms of the framing of the study can be raised. In the first place, the study assumes that, epistemologically speaking, *all knowledge is the same.* For example, students who don't like ambiguity in movies are assumed not to be able to deal with ambiguity in formal knowledge systems (such as science and mathematics). As we have already seen, it is hard to make a case that students should be taught that all scientific knowledge is ambiguous. Secondly, the study assumes that *all learning is the same.* It is a fact that some types of knowledge are relatively quick and effortless to learn (e.g. the sequence of the first 20 elements in the Periodic Table), by comparison with other

knowledge (e.g. the factors that govern bonding between the first 20 elements in the Periodic Table). Also, some people learn quicker than others. It is not therefore valid to conclude that agreement with statements 2 and 4 above implies a view that learning is effortless. Thirdly, *no difficulties in interpreting students' meanings are acknowledged* in the design of the study. For example, the authors do not problematise what students mean when they say that scientists can (or can not) ultimately get to the truth. Philosophers of science, science educators and scientists have argued on each side of this position, using sophisticated arguments. It is not therefore valid to judge students' understanding on the basis of a selection on a 5-point scale.

The work of Songer and Linn (1991) addresses, to some extent, the problem of contextualisation. The study is based upon a sample of 153 North American middle school students. One aim of the study was to investigate the extent to which students' views of science learning correlated with their success at developing an integrated understanding of elementary thermodynamics. Students' views about learning were characterised according to their responses to 21 short answer and true/false questions, all of which were contextualised in science. On the basis of responses to the 21 items, students' views were characterised as *static, dynamic* or *mixed*. Dynamic beliefs, described as 'productive' by the authors, indicated that students 'viewed science as understandable, interpretive, and integrated with many activities in the world around them' (p.769). By contrast, static beliefs (described as 'unproductive') indicated that students 'viewed science knowledge as static, memorization intensive, and divorced from their everyday lives' (p.769). Examples of statements by students holding static and dynamic beliefs are provided by the authors (p.770):

Question	*Static Beliefs Students*	*Dynamic Beliefs Students*
When understanding new ideas, memorizing facts is better than trying to understand complicated material.	'Yes, because if you try and understand complicated material there's a chance you won't understand it, with facts there's just facts.'	'No, sometimes the facts don't give you all the information you need.'

Describe something you learned in a science class that you will never use to explain events outside of school	'Things about chemicals or animals.'	'There isn't one. Everything you learn in science is based on true life.'

The fact that the questions used by Songer and Linn are contextualised in science makes it easier to hypothesise about how students' statements about science learning might influence their behaviour during learning activities. However, learning is still viewed as a uniform process: views of scientific knowledge as static, memorization intensive and divorced from everyday life are portrayed as unproductive. However, most of the scientific knowledge encountered in school by students is indeed pretty static and unrelated to everyday life, and memorization is a key strategy to achieving success in current testing regimes. Furthermore, the approach still has some ambiguities, as can be seen in the classifications of students' statements above. The view that 'with facts there's just facts' appears very close to the view that 'science is based on true life', in the sense that both imply some correspondence between 'facts' in science and elements of the material world, yet the former is classified as static while the latter is classified as dynamic.

What are the messages from this line of research for science education? There is certainly a *prima facie* case that students' views of learning are likely to influence their patterns of study, and that their patterns of study are likely to influence their performance. In spite of the methodological shortcomings of the above studies, there seems to be some empirical evidence of a link between students' questionnaire responses about learning and their performance on science or mathematics learning tasks. However, in order for the research to be useful in informing teaching and learning science it needs to indicate something about the nature of the relationship between views of science and views of learning, or possibilities for teaching. By focusing upon students' behaviour in actual learning situations, future research might illuminate this. The work of Schommer et al. and Songer and Linn does not specify the nature of the relationship in any detail. This body of work might be taken as suggesting that students should be encouraged towards particular views of scientific knowledge and science learning. However, we have seen that learning about epistemology in science involves learning to recognise the different

status of scientific knowledge claims: this position is not commensurate with teaching a dynamic view of science as articulated by Songer and Linn (op. cit.). Furthermore, few would argue that science learning does not involve some learning of factual information.

RESEARCHERS' VIEWS OF SCIENCE LEARNING, AND THE NATURE AND GENERATION OF PUBLIC SCIENTIFIC KNOWLEDGE

So far, this paper has addressed empirical studies of students' and teachers' epistemological perspectives on public scientific knowledge, and on learning. This part of the paper turns attention towards researchers' epistemological perspectives about learning and public scientific knowledge. In contrast to students' and teachers' perspectives, there are no studies that focus explicitly on researchers' epistemological perspectives on public scientific knowledge and learning. Rather, inferences are drawn from academic writing about science learning and the science curriculum.

Recent papers that present overviews of epistemological perspectives on science learning include Seely-Brown, Collins and DuGuid (1989), Hennessy (1993), Driver, Asoko, Leach, Mortimer and Scott (1994), Scott (1998), Tobin, (1998), Anderson, Greeno, Reder and Simon (2000), Sfard (1998), Erickson (2000), and Leach and Scott (2003). Leach and Scott (2003) classify perspectives on science learning as *individual* and *sociocultural*. The main epistemological distinction between these perspectives is the way in which knowledge is portrayed. Most individual perspectives tend to draw upon a Piagetian view of knowledge as located within individuals, and constructed through sensory and other interactions with the world ('constructivist' perspectives); these perspectives have been extremely influential in science education (Erickson, 2000). Individual perspectives on science learning have been criticised on the grounds that they do not adequately account for how individuals come to an understanding of formal, public scientific knowledge that is generated and agreed within communities (Driver et al., 1994). By contrast, sociocultural perspectives portray knowledge as being located within communities of discourse (e.g. Wertsch, 1991). However, sociocultural perspectives have been criticised on the grounds that they do not adequately account for individual differences in knowledge and learning (Leach and Scott, 2003). Drawing upon the debate between psychologists writing from situated and cognitive perspectives, Sfard (1998) identifies

acquisition and *participation* metaphors for learning, arguing that fundamental logical discontinuities between the two metaphors are irreconcilable, yet that both metaphors have their place in explaining human learning.

During the 1990s, a critique on the epistemological perspectives on public scientific knowledge that underpin 'constructivist' research on teaching and learning science was advocated. The most significant challenge to be articulated is that the philosphical underpinnings of constructivism are empiricist and therefore fatally flawed (Matthews, 1992; Matthews, 1997; Suchting, 1992; Nola, 1997). The critique is based upon an analysis of examples of research on teaching and learning science in the 'constructivist tradition'. Examples of texts are used to suggest that constructivist research on teaching and learning is based upon an empiricist view of scientific knowledge as being derived from sensory information, or an extreme relativist view that no knowledge claim can be judged as better, or worse, than another.

A significant body of scholarly writing exists which focuses on the nature and purposes of the science curriculum, reflecting diverse perspectives on the part of authors on the epistemology of public scientific knowledge. A prominent strand in this literature takes constructivist (e.g. Larochelle, Bednarz and Garrison, 1998) or pluralistic (e.g. Aikenhead, 1996; Roberts and Östman, 1998) positions. These epistemological positions have a significant impact on how science curricula are conceptualised. Rather than assuming that the curriculum presents a body of explicit and uncontested knowledge which students must come to understand, it is conceptualised in terms of knowledge and practices into which students are socialised. Aikenhead (1996), for example, uses the metaphor of *border crossing* to describe the way in which the curriculum requires students to move between different ways of knowing about the natural world, while Robers and Östman (1998) refer to *companion meanings* to describe the different layers of explicit and tacit messages about power, status, method and ontology communicated through the science curriculum.

It is possible to divide students who study science into two broad groupings. The first group of students are those who may well go on to study more science in order to enter scientific or technical occupations. Their science education might be conceptualised as a form of pre-professional training, though at the time of schooling it is not possible to

predict whether particular individuals will specialize in science. The second group of students are those who, for whatever reason, will not enter scientific or technical occupations. For them, science education has to have a different rationale. This is typically characterised as science education for citizenship, for scientific literacy or for the public understanding of science. In the remainder of this paper I will use the phrase 'science education for citizenship' to indicate science education for purposes other than pre-professional training.

Various purposes for science education have been proposed, under the general aim of promoting science education for citizenship. Science education for *utilitarian* purposes suggests that some items of scientific knowledge are practically useful to people, and should be included in the curriculum for that reason. However, as argued by Millar (1996), very little curriculum content can be justified on this basis. Science education for *democratic* purposes suggests that citizens of democracies need some scientific knowledge if they are to participate in the democratic process when issues with a science dimension are at stake. Science education for *cultural* purposes assumes that the scientific culture of a society should form a part of the education of future citizens, alongside the music, art and literature of that culture.

The extent to which school science education can ever meet the aspirations of these purposes has been questioned in the literature (see Shamos, 1995; Jenkins, 1999; Millar, 1996). Nonetheless, proposals to develop the science curriculum to address the needs of future citizens all make a case that students need to understand something about the epistemology of public scientific knowledge (e.g. AAAS, 1989; Cross and Price, 1992; Millar and Osborne, 1998; Driver, Newton and Osborne, 2000; Ryder, 2001; Laugksch, 2000; Santos and Mortimer, 2001). If science is taught for democratic purposes, for example, an important aim of teaching is to help students to appreciate something about the social and empirical processes involved in the warranting of knowledge as reliable. In the case of science teaching for cultural purposes, an aim of teaching is to help students to appreciate the interaction of individual scientists' personal creativity, the social and political climate of the day, the empirical methods available and contemporary scientific thinking in the process of creating knowledge. There is now an increasing number of courses which have been developed to address the needs of future citizens, all of which place prominence upon epistemological perspectives on public scientific knowledge (e.g.

the ANW course in the Netherlands; Science for Public Understanding and 21st. Century Science in England).

No single epistemological perspective on public scientific knowledge commands universal agreement. Identifying curriculum content about the epistemology of public scientific knowledge for the purpose of teaching is therefore problematic (Leach et al., 2000), and different proposals can be identified in the literature (Laugksch, 2000). Osborne et al. (2003) report findings from a Delphi study to identify epistemological content about public scientific knowledge thought appropriate for teaching to all British students, by historians, philosophers and sociologists of science, scientists and science teachers. The study suggests that there is some consensus that fundamental epistemological content should be taught, particularly in the area of the methods of science (e.g. the diversity of methods used in science, hypothesising and predicting, cooperation and collaboration) and the nature of scientific knowledge (that some scientific knowledge is well established whereas other scientific knowledge is more open to legitimate doubt). There are other examples of work designed to identify core epistemological content for the science curriculum (e.g. McComas and Olson, 1998). However, much remains to be done to consider how such content might be built in to science curricula, and how teaching activities might be designed and evaluated for teaching such content.

CONCLUSIONS

This section presents conclusions about the scope and nature of epistemological knowledge in relation to teaching and learning science, and considers issues about developing students' epistemological understanding through science teaching.

The scope of epistemological knowledge in research on teaching and learning science

Research has addressed students' and teachers' perspectives on the nature and generation of public scientific knowledge. Studies have addressed teachers' and learners' views of the purposes of science, its demarcation from other ways of knowing, the nature and status of scientific knowledge and its relationship to evidence, and social and institutional dimensions in the warranting of knowledge claims as reliable.

Studies have also been conducted about students' and teachers' views of learning, that is, knowledge generation by individuals.

The nature of epistemological knowledge

Evidence was presented that individuals appear to draw upon different epistemological knowledge according to the task that they are involved in. An important characteristic of epistemological expertise in science is the ability to use epistemological knowledge appropriately in different situations. Studies have been conducted which, depending upon the methodology used, have characterised students' and teachers' explicit epistemological knowledge, or the tacit knowledge that appears to guide their actions in various situations. There is some evidence that students' and teachers' explicit statements about epistemology may not be good predictors of their actions in situations which require (tacit) epistemological knowledge to be used. Evidence was also presented which suggests that individuals may make naïve statements about epistemology, but may nonetheless be able to perform tasks with a tacit epistemological dimension in a sophisticated way.

Evidence from a range of studies which are based upon different methodologies suggests that many students do not recognise the ontological status of many of the entities used in scientific explanations. Entities such as 'gene' and 'force' are seen as detailed descriptions of objects in the material world, rather than as objects with particular attributes that have been defined for specific purposes in science. As more advanced students begin to problematise the ontological distinction between the objects of scientific explanations and the objects of the material world, there is evidence that some resolve the problem through radical relativism.

Evidence has been presented in the literature which suggests that there is a relationship between individual students' views of learning, and their achievement in science. The nature of this relationship is, however, unclear.

In this paper, the term 'epistemological knowledge' is used to refer to the personal knowledge that individuals appear to use in given situations. Given that this is often tacit, and has certainly not been exposed to any processes designed to warrant it as reliable,

such ‘knowledge’ might better be referred to as ‘epistemological beliefs’. This would distinguish it from explicit perspectives that have been generated in the science studies disciplines.

Developing students’ epistemological understanding through science teaching

People develop epistemological knowledge about science as a result of studying science content and living in a world where science and technology are prominent, even when no formal attempt is made to teach about epistemology in science. A significant amount of scholarship has been conducted to examine how the science curriculum might be designed to enable students to develop more powerful and justifiable epistemological knowledge. Three main approaches to teaching epistemology through science education can be seen in the literature. The first of these is teaching science studies content explicitly, and various authors have suggested how content might be selected and taught. The second approach involves making epistemological features of conceptual science content explicit to learners, and selecting content in order to make particular features of epistemology explicit. The third approach involves putting students in learning situations that mimic aspects of authentic scientific practice.

Bibliography

AAAS (1989). *Project 2061: benchmarks for scientific literacy*. Washington DC: AAAS.

Aikenhead, G. S., Fleming, R. W. and Ryan, A. G. (1987). High school graduates’ beliefs about science-technology-society 1. Methods and issues on monitoring student views. *Science Education, 71* (2), 145-161.

Aikenhead, G. S. (1996). Science education: order crossing into the subculture of science. *Studies in Science Education, 27*, 1-52.

Anderson, J. R., Greeno, J. G., Reder, L. M. and Simon, H. A. (2000). Perspectives on learning, thinking and activity. *Educational Researcher, 29*(4), 11-13.

Bell, R. F., Abd-El-Khalik, F., Lederman, N. G., McComas, W. F. and Matthews, M. R. (2001). The nature of science and science education: a bibliography. *Science and Education, 10* (1/2), 187-204.

Brickhouse, N. W. (1990). Teachers’ beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education*, *41*, 53-62.

Brickhouse, N. W., Dagher, Z. R., Shipman, H. L. and Letts, W. J. IV. (2000). In R. Millar, J. Leach and J. Osborne (Editors): *Improving science education: The contribution of research.* Buckingham, UK: Open University Press.

Cartier, J. L. and Stewart, J. (2000). Teaching the nature of inquiry: Further developments in a high school genetics curriculum. *Science and Education, 9*, 247-267.

Cross, R. T. and Price, R. F. (1992). *Teaching science for social responsibility*. Sydney, Australia: St. Lewis press.

Désautels, J. and Larochelle, M. (1997). The epistemology of students: the 'thingified' nature of science. In B. Frazer and K. Tobin (Editors): *International Handbook of Science Education*. Dordrecht, NL: Kluwer.

Driver, R., Asoko, H., Leach, J., Mortimer, E. and Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23, (7)*, 5 - 12.

Dirver, R., Leach, J., Millar, R. and Scott, P. (1996). Young People's Images of Science. Buckingham, UK: Open University Press.

Driver, R., Newton, P. and Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84* (3), 287-312.

Duschl, R. A. (1990). *Restructuring science education: the importance of theories and their development.* Teacher's College Press.

Erickson, G. (2000). Research programmes and the student science learning literature. In R. Millar, J. Leach and J. Osborne (Editors): *Improving science education: the contribution of research*. Buckingham, UK: Open University Press.

Fleming, R. W. (1987). High school graduates' beliefs about science-technology-society 2: the interaction amongs s science, technology and society. *Science Education, 71*, 163-186.

Galili, I. And Hazan, A. (2001). The effect of a history-based course I n optics on students' views about science. *Science and Education*, *10* (1/2), 7-32.

Halloun, I. And Hestenes, D. (1998). Interpreting VASS dimensions and profiles for physics students. *Science and Education, 7*, 553-577.

Hennessy, S. (1993). Situated cognition and cognitive apprenticeship: implications for classroom learning. *Studies in Science Education, 22*, 1-41.

Hodson, D. (1993). Philosophic stance of secondary school science teachers, curriculum experiences, and children's understanding of science: some preliminary findings. *Interchange*, *24 (1 and 2)*, 41-52.

Jenkins, E. W. (1999). School science, citizenship and the public understanding of science. *International Journal of Science Education, 21* (7), 703-710.

Kelly, G. J., Chen, C. and Crawford, T. (1998). Methodological considerations for studying science-in-the-making in educational settings. *Research in Science Education*, *28* (1), 23-49.

Kuhn, D. (1991). *The skills of argument*. Cambridge: Cambridge University Press.

Larochelle, M. and Désautels, J. (1991). 'Of course, it's just obvious': adolescents' ideas of scientific knowledge. *International Journal of Science Education, 13* (4), 373-389.

Larochelle, M., Bednarz, N. and Garrison, J. (Editors)(1998). *Constructivism and Education*. Cambridge: Cambridge University Press.

Laugksch, R. C. (2000). Scientific literacy: a conceptual overview. *Science Education, 84* (1), 71-94.

Leach, J. (1996). Student's understanding of the nature of science. In G. Welford, J. Osborne and P. Scott (Editors): Research in science education in Europe: Current issues and themes. London: Falmer Press.

Leach, J. (2002a). *Students' understanding of the nature of science and its influence on labwork.* In D. Psillos and H. Niedderer (Editors): *Teaching and learning in the science laboratory.* Dordrecht, NL: Kluwer.

Leach, J. (2002b). The use of secondary data in teaching about data analysis in a first year undergraduate biochemistry course. In D. Psillos and H. Niedderer (Editors): *Teaching and learning in the science laboratory*. Dordrecht, NL: Kluwer.

Leach, J., Millar, R., Ryder, J. and Séré, M-G. (2000). Epistemological understanding in science learning: the consistency of representations across contexts. *Learning and Instruction, 10 (6)*, 497-527.

Leach, J. and Scott, P. (2003). Individual and sociocultural perspectives on learning in science education. *Science and Education, 12* (1), 91-113.

Leach, J., Hind, A. and Ryder, J. (203). Designing and evaluating short teaching interventions about the epistemology of science in high school classrooms. *Science Education*, *87*, 831-848.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: a review of the research. *Journal of Research in Science Teaching*, *29 (4)*, 331-359.

Lederman, N. G., Abd-El-Khalik, F., Bell, R. L. and Schwartz, R. S. (2002). Views of Nature of Science questionnaire: towards valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*, 497-521.

Lederman, N. G., Wade, P. D., & Bell, R. L. (1998). Assessing understanding of the nature of science: A historical perspective. In W. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 331-350). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Le Maréchal, J-F. (1998). Modelling student's cognitive activity during resolution of problems based on experimental facts in chemical education. In J. Leach and A. Paulsen (Editors): *Practical work in science education: recent research studies.* Dordrecht, NL: Kluwer.

Lewis, J. (2002). The Effectiveness of Mini-Projects as a Preparation for Open-Ended Investigations. In D. Psillos and H. Niedderer (Editors): *Teaching and learning in the science laboratory.* Dordrecht, NL: Kluwer.

Matthews, M. (1992). Constructivism and empiricism; an incomplete divorce. *Research in Science Education*, *22*, 299-307.

Matthews, M. (1994). Discontent with constructivism. Review of 'The content of science: a constructivist approach to its teaching', edited by P. Fensham, R. Gunstone and R. White. London: Falmer. *Studies in Science Education*, *24*, 165-172.

Matthews, M. (1997). Introductory comments on philosophy and constructivism in science education. *Science and Education*, *6*, 5-14.

McComas, W. F. and Olson, J. K. (1998). The nature of science in international science education standards documents. In W. F. McComas (Editor), *The nature of science in science education: rationales and strategies.* Dordrecht: Kluwer.

Millar, R. (1996). Towards a science curriculum for the public understanding of science. *School Science Review*, *77 (280)*, 7-18.

Millar, R. and Osborne, J. (1998). Beyond 2000 – Science education for the future. London: King's College London.

Nola, R. (1997), Constructivism in science and science education: a philosophical critique. *Science and Education*, *6*, 55-83.

Osborne, J, Ratcliffe, M., Millar, R. and Duschl R. (2003). What 'ideas about science' should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692-720.

Roberts, D. A. and Östman, L. (Editors) (1998). *Problems of meaning in science curriculum.* New York: Teachers College Press.

Roth, W-M. (1995). *Authentic school science: knowing and learning in open-inquiry science laboratories.* Dordrecht: Kluwer.

Roth, W-M. and Bowen, G. M. (1999). Complexities of graphical representations during ecology lectures: an analysis rooted in semiotics and hermeneutic phenomenology. *Learning and Instruction, 9,* 235-255.

Roth, W-M. and Roychoudry, A. (1994). Physics students' epistemologies and views about knowing and learning. *Journal of Research in Science Teaching*, *31*(1), 5-30.

Rowell, J. A. and Dawson, C. J. (1983). Laboratory counterexamples and the growth of understanding in science. *International Journal of Science Education, 5,* 203-215.

Ryder, J. (2001). Identifying science understanding for functional scientific literacy. *Studies in Science Education, 36*, 1-44.

Ryder, J. (2002). Data interpretation activities and students' views of the epistemology of science during a university earth sciences field study course. In D. Psillos and H. Niedderer (Editors): *Teaching and learning in the science laboratory.* Dordrecht, NL: Kluwer.

Ryder, J., Leach, J. and Driver, R. (1999). Undergraduate science students' images of the nature of science. *Journal of Research in Science Teaching, 36 (2*), 201-220.

Ryder, J. and Leach, J. (2000) Interpreting experimental data: the views of upper secondary school and university science student., *International Journal of Science Education, 22* (10), 1069-1084.

Ryder, J. and Leach, J. (1999). University science students' experiences of investigative project work and their images of science. *International Journal of Science Education*, *21* (9), 945-956.

Samarapungavan, A. (1992). Scientists' conceptions of science: a study of epistemic beliefs. Paper presented at the meeting of the American Educational Research Association, San Francisco, April 1992.

Sandoval, W. A. and Morrison, K. (2003). High school students' ideas about theories and theory change after a biology enquiry unit. *Journal of Research in Science Teaching*, *40*(4), 369-392.

Santos, W. L. P. dos and Mortimer, E. F. (2001). Approaching socio-scientific issues in classrooms: a case study. Paper presented at the annual meeting of the European Science Education Research Association, Thessaloniki, Greece, August 2001.

Schommer, M., Crouse, A. and Rhodes, N. (1992). Episltemological beliefs and mathematical text comprehension: believing it is simple does not make it so. *Journal of Educational Psychology, 84 (4),* 435-443.

Scott, P. (1998). Teacher talk and meaning making in science classrooms: a Vygotskian analysis and review. *Studies in Science Education*, *32*, 45-80.

Seely Brown, J., Collins, A. and DuGuid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Séré, M-G., Journeaux, R. and Larcher, C. (1993). Learning the statistical analysis of measurement errors. *International Journal of Science Education, 15* (4), 427-438.

Séré, M-G., Fernandez-Gonzalez, M., Gallegos, J. A., Gonzalez-Garcia, F., De Manuel, E., Perales, F. J. and Leach, J. (2001). Images of science linked to labwork: a survey of secondary school and university students. *Research In Science Education, 31*, 499-523.

Séré, M-G. and Guillon, A. (2002*). The role of epistemological knowledge in the effectiveness of open-ended investigative labwork*. In Psillos, D. and Niedderer, H. (Editors): *Teaching and learning in the science laboratory*. Dordrecht, NL: Kluwer.

Sfard, A. (1998). On two metaphors for learning and the danger of choosing just one. *Educational Researcher, 27*(2), 4-13.

Shamos, M. (1995). *The myth of scientific literacy*. New Brunswick, NJ: Rutgers University Press.

Songer, N. B. and Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching, 28*, 761-784.

Suchting, W.A. (1992). Constructivism Deconstructed. *Science and Education, 1*, 223-254.

Tiberghien, A. (1996). Construction of prototypical situations in teaching the concept of energy. In A. G. Welford, J. Osborne and P. H. Scott (Editors): *Research in science education in Europee: Current issues and themes*. London: Falmer.

Tiberghien, A. (2000). Designing teaching situations in the secondary school. In R. Millar, J. Leach and J. Osborne (Editors): *Improving science education: the contribution of research.* Buckingham, UK: Open University Press.

Tiberghien, A. and Megalakaki, O. (1995), Characterisation of a modelling activity for a first qualitative approach to the concept of energy. *European Journal of Psychology of Education, 10(4),* 369-383.

Tobin, K. (1998). Sociocultural perspectives on the teaching and learning of science. In M. Larochelle, N. Bednarz and J. Garrison (Eds): Constructivism and Education. Cambridge: Cambridge University Press.

Vollebregt, M. J. (1998). A problem posing approach to teaching an initial particle model. Utrecht: Centre for Studies in Science and Mathematics Education.

Wertsch, J.V. (1991). *Voices of the Mind: A Sociocultural Approach to Mediated Action*. Harvester Wheatsheaf.

Ziman, J. (1978). *Reliable knowledge.* Cambridge: Cambridge University Press.