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A framework for practical work in science and scientific literacy through argumentation

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This paper draws on earlier work on ideas that underpin the collection and use of evidence in science in schools. It establishes that different types of practical work share the same procedural underpinnings. It then takes the work of Toulmin on argumentation to suggest that the idea of the 'public claim' can be used to forge a link between scientific experimentation in schools and emerging ideas of scientific literacy. It concludes with a discussion of possible implications.

Introduction

Over the past 40 years or more practical work in school science has been a contentious subject. Arguments have been made, *inter alia*, for its development, replacement by different styles of practical work, or abandonment as not producing any measurable gains in understanding. More recently the science education community has turned its collective attention to the idea of scientific literacy. Lang *et al.* (2006) cite the increasing calls for the science curriculum to reflect the real world needs of students so that they can participate in science debates. In this paper we should like to contribute to the debate on these issues by proposing a framework within which practical work, scientific literacy and, in particular, argumentation (or at least elements of each), can be located.

Our purpose is not to suggest that there is an obvious way forward—although we have our own views which will no doubt condition what we write here—but to propose this framework so that the science education community can judge the extent to which it might inform the debate. In developing this framework, we shall begin with a brief review and critique of practical work as it has developed in the UK over

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the past few years. Between this background section, and a final section on implications for teaching, we shall use two substantive sections to develop our argument.

In the first we shall attempt to show how various types of practical work have a common basis in the ideas needed to understand scientific evidence. These ideas we have discussed elsewhere as 'concepts of evidence' (Gott *et al.*, 2003). We shall show how these ideas, structured by experimental design, culminate in a conclusion or claim. In the second, we use Toulmin's work on argumentation to provide us with a theoretical perspective which links data collection and verification, argumentation and (elements of) scientific literacy. To do this, we shall look at the central role of the 'claim' and suggest that Toulmin's model can be used as a structure both for constructing a claim and for a *post hoc* examination of the claims of others (which we see as a crucial element of scientific literacy).

It will be useful here to emphasise a point which has guided our thinking: the idea of public or private 'claims'. As an experiment is being carried out, an eye should always be kept on the claim that will be constructed from the experimental design and the resulting data. This claim, which may form the basis for a scientific article say, will be made at the point at which the work is deemed to be sufficiently robust to be made 'public' and subjected to critical scrutiny. Claims at this level are then disseminated as popular, and often populist, press articles, or they may appear in other forums such as planning enquiries or as forensic evidence in courts. Practical work in schools approaches the claim in much the same way. It requires pupils to construct a private claim (we use 'private' here to indicate that the claim is a personal one, made to oneself, or to the class teacher) which they should be able to defend. From the standpoint of scientific literacy, we must find a way for pupils to see that the ideas that go into constructing their own claim can also be used to help in deconstructing the public claims of others. This involves looking back from the public claim to its origin, asking questions like: 'Could this idea be tested?', 'Could this set of observations and measurements, carried out in this way, *possibly* give reliable data on this question?' and 'Are there alternative explanations of the data?' The claim thus becomes a key element in bridging the gap between pupils' work in the school laboratory (or in the field) and claims about science in the media or other publications.

Practical work

Practical work in the UK science curriculum has evolved through a series of stages over recent years. Prior to the National Curriculum (DES, 1989) and up to the age of 16-years-old, there was a tendency for most practical work to be illustrative in nature, either through the demonstration of a concept or law, or by guiding pupils to 'discover' these concepts or laws for themselves (Nuffield Foundation, 1966). The notion of 'arriving at the right answer' was central. In 1989, The National Curriculum for England and Wales heralded a major change: practical work now involved more open investigations with a focus on the 'fair test'.[1] These were primarily laboratory-based tasks and encouraged pupils to design their own investigations and collect and interpret their own data, albeit in a rather restricted range of contexts. The structure usually comprised one independent and one dependent variable, although higher levels sometimes involved more than one independent variable. Concerns about the restrictive nature of these tasks (House of Commons, Science and Technology Committee, 2002) have led to the recently revised curriculum due for implementation in 2006, which will encourage teachers to include field work, the use of secondary sources of data, and the consideration of societal issues in relation to the understanding and use of evidence (QCA, 2005). While the recent changes are to be welcomed and go some way towards broadening the curriculum, the range of formally assessed practical work actually carried out in science classrooms across the country remains limited in scope. For example, tasks such as fault finding in electrical circuits, biological surveys or observation tasks such as chemical analysis, or plant or animal identification, are not normally included (although that does not, of course, mean that teachers do not use them in their teaching). However, because these kinds of tasks have not been specified in the curriculum, there is a natural tendency for curriculum developers, textbook writers and teachers to overlook them.

If one of the aims of science education is to expose pupils to a range of scientific methods, then it follows that there is a case for incorporating a wider range of practical tasks. At the same time, there needs to be clarity about which types to include and a coherent model that indicates their 'position' in relation to the, now more familiar 'fair tests'. With such a framework in place, we can then make a judgement as to how and when to incorporate them into the curriculum. We may also decide that some types of practical work should not be included at all. That decision depends on their purpose. The underlying position we adopt here is that one key purpose, at least for most pupils, is to understand how public claims from experimental data come to be made, and how factors in the design and collection of the data determine the weight which can be placed on them. We shall draw the examples from work typical of the 11–16 age range but the framework is not intended to be so restricted.

Types of practical work

Here we will outline three broad types of practical work. We recognise that there are other possibilities[2] but we have chosen these types because they enable us to make a number of points as simply as possible. The types are:

1. Simple tasks with two variables (independent and dependent) of the type which has been the norm in the National Curriculum assessment arrangements.
2. Fieldwork, which has now been introduced into the National Curriculum for 2006, but has been omitted heretofore.
3. Diagnostic or fault-finding tasks, which are currently *not included* at all.

Each type will be exemplified, briefly, in the following sections. We shall identify their distinguishing characteristics and then show that there is a set of ideas which underpin them all and which structure the pupils' 'private claim'.

A simple laboratory task. Let us begin with an example of a relatively simple open investigation:

- Find out how the length of a bridge affects how much it sags.

The usual procedure would be for pupils or the teacher to simulate a bridge by using different lengths of wood or metal and then measure the sag with an appropriate weight. Their data might look something like Table 1.

Such a task requires pupils to decide which variables are important in designing the task and which need to be controlled in some way. They will then need to choose appropriate measuring instruments and set up the apparatus in such a way as to allow the measurements to be taken accurately and over a sensible range and interval. To be sure of the reliability of their findings, they would repeat the measurements several times with each length of bridge and calculate the mean sag. They would then examine the pattern in the data and in this case, conclude that the longer the bridge the greater the sag and, perhaps, that the relationship appears to be linear. This is their 'private claim'. They might also compare their findings with others in the class.

Field investigations. Consider a biological survey or field investigation, such as

- What determines the location of plant X (e.g., a wild flower)?

Pupils would be expected to use their ecological knowledge to select and measure a range of possible independent variables such as degree of light/shade, mean daily temperature, rainfall and an appropriate dependent variable, for example, the density of plant X. The issue of reliability would be addressed in part by repeating the exercise in several different areas to produce a data set which could resemble Table 2, which again is purely illustrative.

The analysis would then involve looking for a pattern in the data. There are different ways of doing this. Students could examine each independent variable in turn and also in combination. The usual starting point is to order the variable of interest, in this case, plant density. Doing so suggests that plant density increases with increasing shade (a correlation); a 'private claim'. The relationship with temperature is less clear but suggests that density increases with lower temperatures.

Table 1. Data table from an investigative school laboratory task

Trials	Sag of bridge (cm)				
Length of 'bridge'	*20cm*	*30cm*	*40cm*	*50cm*	*60cm*
1	1.2	1.5	2.1	2.5	2.8
2	0.9	1.3	1.8	2.4	3.1
3	0.9	1.6	1.9	2.2	3.3
4	1.1	1.5	2.0	2.7	3.0
Mean	1.0	1.5	2.0	2.5	3.1

Table 2. Data table from a fieldwork task

Area	Density of plant X (/m^2)	Shade (mean %/ daylight hours in shade)	Mean daily temperature °C	Rainfall
1	10	42	11	High
2	12	46	12	Low
3	15	50	9	Medium
4	19	54	10	High
5	20	57	9	Low
6	25	62	8	High

So there is likely to be more than one step in analysing the data, simply because there is usually more than one independent variable to consider. Another possible way of considering the multivariate nature of field data is to simplify it by 'slicing' the variables into defined categories of 'high' and 'low' values, and then construct cross-tabulations of counts of number of areas with the defined conditions as in Table 3. More complex multivariate analysis techniques might also be used if there are sufficient data.

Following analysis, a useful discussion could be instigated here about the narrow range of temperatures tested and the possibility of an association (chance or otherwise) or a causal relationship. The data might also lead to the suggestion that the density of this wild flower is independent of rainfall (another 'private claim'), while acknowledging the limitations of the sample size for interpretation.

There are significant differences between a field investigation of this kind and the bridge investigation described earlier. In terms of design, for example, we can see that in the field investigation, the investigator sets out with broad questions or hypotheses in mind. Details of the question(s) are often determined *after* the data collection (Roberts & Gott, 2003). In fieldwork of this kind, it is sensible to collect data on as many factors as possible while on site. Decisions can be made later as to how to 'cut' the data to explore possible factors that, for example, may define the parameters of a particular habitat. There are many different ways of doing this. Unlike the bridge example, there are more than two variables in our field investigation and so the analysis is more challenging in that additional thinking is required to select and consider possible relationships. Another difference in these two types of practical work is the underlying methodology. In field investigations it is often not possible to carry out 'a fair test' and time may be a pertinent variable: collecting longitudinal data may be the most important aspect. For example, the density of plant X could be examined at yearly intervals to monitor change. The field investigation also lends itself to considerations of the problems associated with the interpretation of multivariate data such as that of distinguishing between causation and association. There may also be comparable published data. Field investigations such as this can be used to lead pupils into discussions of the sorts of problems encountered in trying to gather evidence about other kinds of environmental issues.

Table 3. Alternative data presentation from a field work task (counts of areas)

	Shade			Temperature			Rainfall		
Plant density	Low $<50\%$ daylight hrs. of shade	High $\geq 50\%$ daylight hrs. of shade	**Plant density**	Low $<10°C$	High $\geq 10°C$	**Plant density**	Low	Medium	High
Low $<16/m^2$	2	1	Low $<16/m^2$	1	2	Low $<16/m^2$	1	1	1
High $\geq 16\ m^2$		3	High $\geq 16\ m^2$	2	1	High $\geq 16\ m^2$	1		2

Diagnostic or fault-finding tasks. Our third type involves a series of sequential, often qualitative tasks, rather than a single task. Consider for instance electrical fault-finding, medical diagnosis ('human fault-finding'), forensic science, biological taxonomy or qualitative analysis in chemistry. We shall take the last of these as an example. The task here is to go through a series of tests to identify an unknown chemical substance or, as in Figure 1, to distinguish within a set of known substances.

Figure 2 illustrates one possible solution.

Each of the tests leads to a claim. For example, at the first stage in the process, if there is a white precipitate, then we can state that the substance is either aluminium or magnesium sulphate. Each stage helps to eliminate and narrow down the choices. Negative results (e.g., no precipitate) are as important in providing information as positive results. Each test is based on qualitative data or observation which can, in itself, be regarded as a form of measurement[3] and must be carried out in a 'fair test' fashion for the result to be valid and reliable. For example, if 'excess' sodium hydroxide was not in fact excess, then the precipitate will remain leading to a 'misdiagnosis'. If there was any doubt about the results of a test, then it would need to be repeated. Each of the tests can be seen, individually, as an investigation in its own right and each in turn must therefore be subject to tests of reliability and validity. This structured key (Figure 2) is a representation of the 'truth table' based on Boolean algebra in which there are two 'states': present (1) or absent (0) as in Table 4. It is the configuration of the sequential results (present/absent) which leads to the 'diagnosis'.

Unlike the previous examples, here there are several tasks which, although each is an investigation in its own right, are all linked in a particular logical sequence. In the previous fieldwork task the requirement is one of *selection of data;* here it is the *selection of tasks* in the most effective and parsimonious order. To succeed, the pupil has to reason or argue with him/herself or with others to proceed from one step to the next. There is a large literature base on such 'diagnostic' skills in the medical area where the novice doctor has not yet acquired the experience to decide on the quickest route to a solution. Protocols exist for nurses to collect routine information to start off the 'truth table', after which the skilled diagnostician will select additional tests in a particular order until they are sufficiently confident in their conclusion or 'claim' to reach a diagnosis and proceed to treatment (see, for instance, Coderre *et al.*, 2003).

You will be given unlabeled samples of the four following ionic compounds

- magnesium sulphate
- aluminium sulphate
- ammonium sulphate
- sodium sulphate

Can you carry out / plan a range of chemical tests to identify each of them?

Figure 1. A diagnostic task

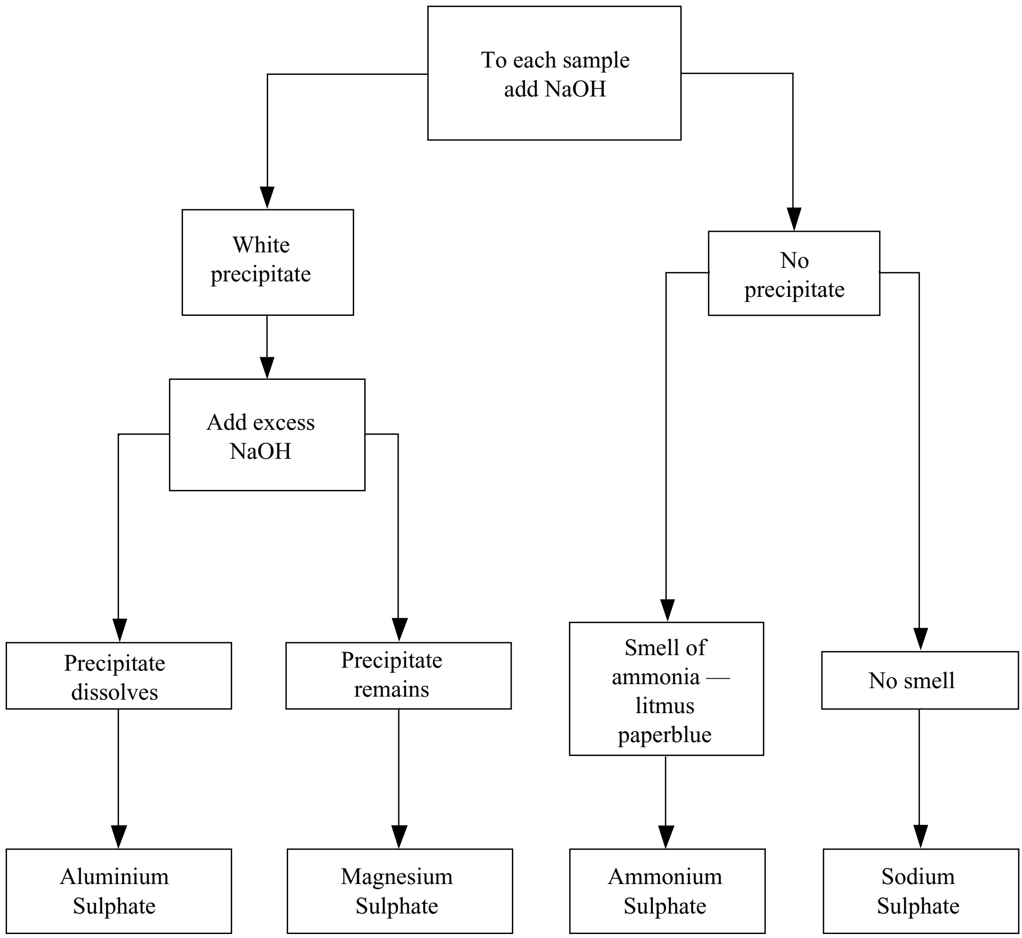

Figure 2. Steps in the solution of the diagnostic task

Table 4. Data table from a diagnostic task (there are of course a possible eight rows in this table but some become redundant)

White precipitate with sodium hydroxide	Smell of ammonia	Dissolves in excess sodium hydroxide	Conclusion or 'private claim'
1	Not relevant	1	Aluminium sulphate
1	Not relevant	0	Magnesium sulphate
0	1	Not relevant	Ammonium sulphate
0	0	Not relevant	Sodium sulphate

Concepts of evidence

How do these various sorts of practical work relate to the underlying ideas needed to understand scientific evidence? To answer this question, we need to return to the idea of concepts of evidence to which we referred briefly earlier. These are the ideas which lie behind the understanding of scientific evidence and which structure the design of an investigative task. They underpin reliability and validity and include ideas such as the purpose of controlling variables, aspects of measurement such as sampling, accuracy and precision or the relative strength of continuous or interval measurement as compared to nominal or categoric measurement. They also include evaluating evidence in the wider context of societal issues and factors such as cost, possible bias/interest of the experimenters, etc. We have produced an extended list of these ideas (Gott *et al*., 2003) and their structure is summarised in Figure 3, below.

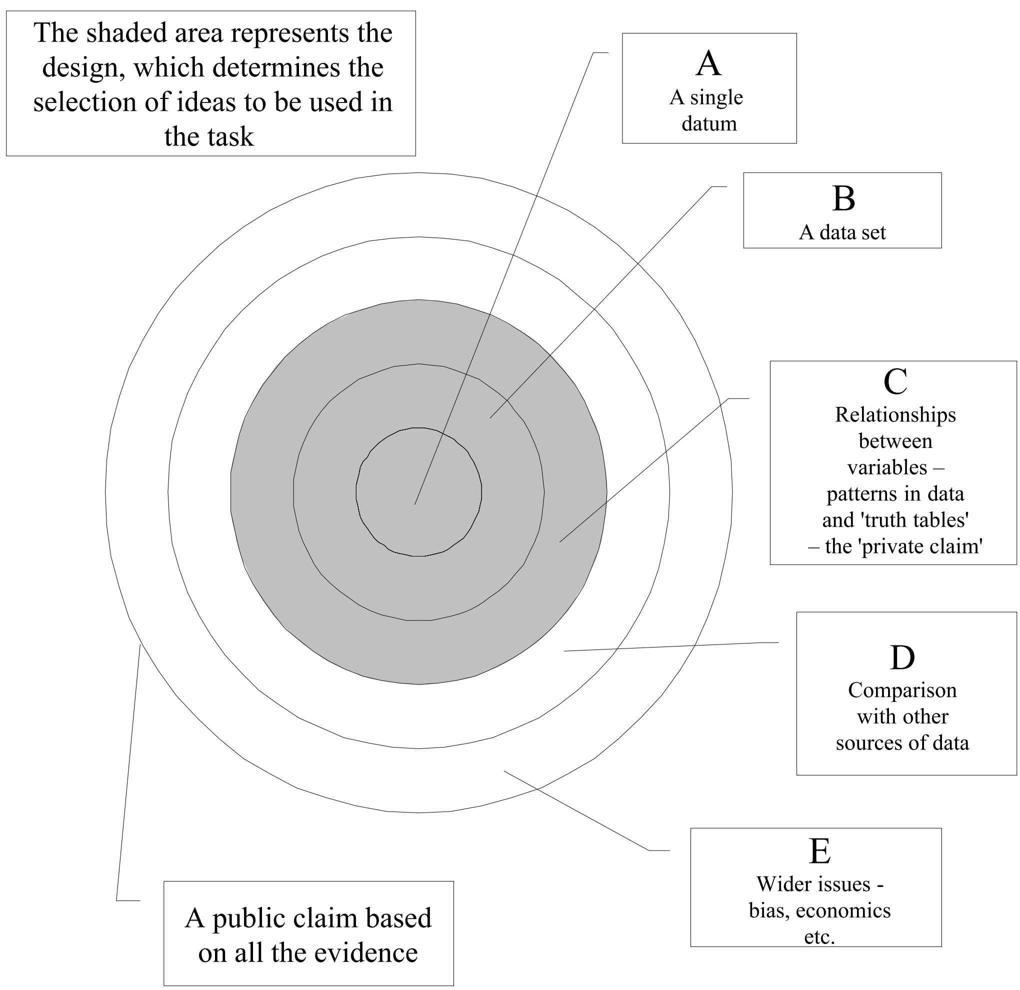

Figure 3. Concepts of evidence

The innermost circle represents the most basic element of any experiment—the creation of a single datum, be it a measurement or a categorical observation. Circles A, B and C represent the ideas needed for the simple investigations we have discussed earlier. An experimental design draws on whichever elements of A, B and C are deemed to be necessary to satisfactorily answer the question under investigation. This results in a 'private claim'. We can note here, for use later, that the outer perimeter is the point at which a '*public* claim' is made in response to that question, again drawing on A to C, but also on D and E where appropriate and where a broader context for the claim and its link to existing findings is made. A distinction can be drawn between how the broader ideas of D and E are important in defining the way the task is conducted (insufficient funds for an expensive measuring instrument perhaps) and how the claim is weighed *alongside* these issues in reaching a practical decision. We shall not explore that distinction here for want of space.

If we now think back to the bridge investigation, by making measurements, collecting and analysing the data, pupils will begin to understand the ideas in the innermost three circles in Figure 3 (A, B and C) and start to make 'private claims'. By comparison with other groups in the class pupils are also beginning to understand some of the ideas in circle D. However it is difficult to see how there is much scope for understanding wider issues (E) with this relatively simple type of investigation. The field investigation example also allows pupils to make measurements, collect and analyse data using the ideas in circles A, B and C. As discussed above, fieldwork tends to open up a number of issues which laboratory work does not and so allows opportunities to extend the concepts of evidence to which pupils are exposed. Comparing the data with published data (if it was available) would also allow pupils to expand their 'private claims' and access some of the ideas in circle D. In fieldwork of this kind, it is also easier to envisage how a meaningful discussion of wider issues such as the likelihood of the habitat surviving or the pressures on land use for, and from, agricultural purposes (circle E) could be facilitated. Turning to the diagnostic tasks, pupils will need to work with an understanding of the ideas in circles A, B and C. Since they have to use the results from one test to decide if they need to do further tests (and if so which one), pupils will need to look carefully at their data using the ideas in circle C, for their diagnosis.

So far we have not mentioned 'design' specifically. Our list of concepts of evidence (Gott & Duggan, 2003) provides a sort of 'tool box' from which an investigator selects the elements most appropriate to a particular design. In terms of school science, if pupils are encouraged to formulate a question and/or design a task for themselves, then they will probably make some kind of plan of the design to begin the practical work. The experienced pupil or investigator[4] will modify the design appropriately as the investigation unfolds and will probably need to repeat the investigation more than once in an iterative fashion to arrive at a design which will yield the data needed to answer the original question. The pupil (or group of pupils) is then required to come to some kind of conclusion and make a statement or a 'private claim' about their data. This may be in the form of a report or it may be a class discussion (see Figure 4).

To summarise, we have seen that these three types of tasks allow pupils to access a range of concepts of evidence. All the tasks allow pupils to work with a single datum,

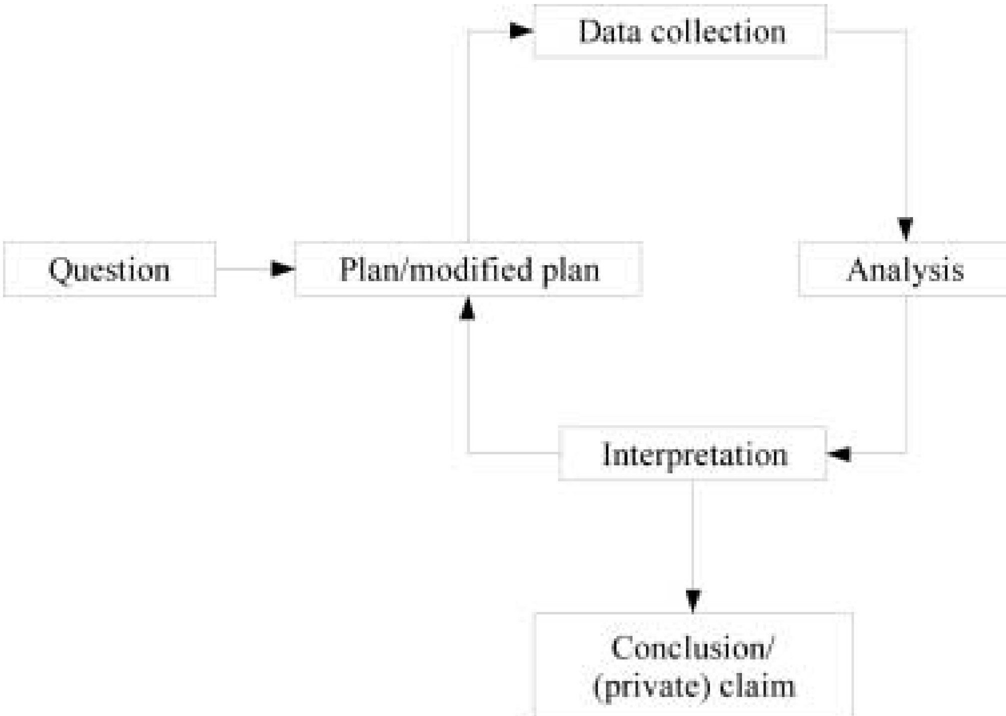

Figure 4. The investigation process

a data set and to look for patterns and relationships between the variables—the inner-most three circles in Figure 3. Some types of practical work can also be used to encourage pupils to compare their results with other data and to explore wider issues. The tasks culminate in a claim. So in this way, pupils are exposed to the reality of the design and collection of data which enables a claim to be made. The next step is to consider encountering the claim from the other end as it were, without the personal experience of having collected the data. We are now looking at the diagram in Figure 3 from the outside. For it is in relation to the outer circles that the link to 'scientific literacy' is most apparent.

Scientific literacy and school science

A significant part of scientific literacy requires an understanding of evidence and its underlying ideas in order better to understand public claims and their popular and populist derivatives. We are, of course, making an assumption here that scientific literacy should, at least in part, be about empowering the citizen of the future to challenge decisions with some confidence that they can at least ask sensible questions. This critical appreciation of science is founded on a belief that evidence (not a claim) is of the essence: as the Royal Society motto has it—'*Nullius in Verba*' ('On the words of no

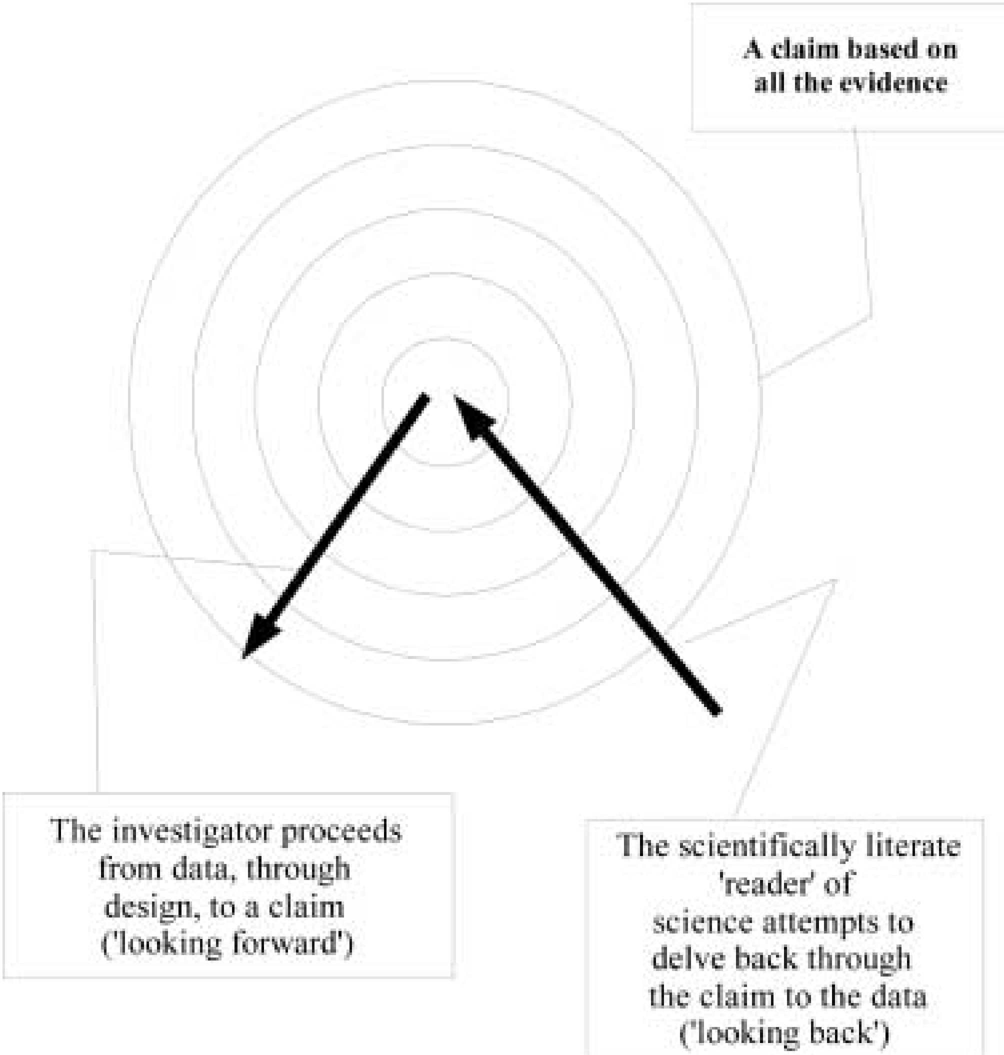

Figure 5. Looking forward and looking back

one'), indicating a commitment to establishing the truth through experiment and observation rather than through the citation of authority (Royal Society, website).

To engage with a scientific issue in an informed way, we need to be able to look 'behind the public claim' and consider the design, data collection and analysis required to support that claim (Figure 5). We have referred to this retrospective process before as 'looking back' in contrast to most school science practical work which can be regarded as 'looking forward' (Gott & Duggan, 2003).

The kinds of practical work described in the last section provide excellent practice in the 'hands-on' doing of science, encouraging pupils to 'look forward' by designing an investigation and collecting, analysing and interpreting data, and presenting their claim. But if school science is to equip pupils to be scientifically literate then it also needs to encourage pupils to 'look back' from the scientific public claims which they are likely to meet in daily life.

When we consider such issues as global warming, cloning or the debate about future energy sources, the problem is that they are a long way from the kind of tasks which can be feasibly undertaken in school science. Issues like global warming are so complex and controversial that experts themselves will disagree about the interpretation of the data. Assuming we could obtain relevant data, it will not be accessible to many pupils although they will have opinions about such things as the ethics of the issue, or potential bias of scientists, as indeed they are encouraged to do in this and other curriculum areas. Although such debate is valuable in itself and clearly addresses the ideas about evidence in the outermost circle (E in Figure 3), it is so far removed from the practical laboratory task that it is hardly surprising that pupils, and teachers, have difficulty making a connection.

But if data are available, and in a form which is not too difficult to come to terms with, then it should be possible to 'look back' from the claim into the investigation by considering the arguments which have created the claim and which constitute the forum for debate. To do that we need a structure which allows us to think about how claims are made and where data and design fit. It is here that the work of Toulmin in structuring the pattern or layout of rational argument may be helpful.

Toulmin and argumentation

Toulmin's book *The uses of argument* (Toulmin, 1958) can be seen as an extended analogy between evidence in argumentation and the proceedings of a court of law:

> We can get some hints (about the phases in an argument), if we consider the parallel between the judicial process, by which the questions raised in a court of law are settled, and the rational process, by which arguments are set out and produced in support of an initial assertion. (Toulmin, 1958, p. 15)

The parallels between Toulmin's legal examples and the case of experimental science are close, to the extent, of course, that parts of the judicial process are precisely an examination of the (forensic) scientific evidence. So we can think of the whole scientific investigatory process in similar terms. The scientist collects evidence in a reliable and valid manner and makes claims as a consequence. Toulmin's key terms which, he suggests, constitute the elements of rational argument are:

- *Data.* The grounds or the facts which are the foundation for the 'claim'. In the case of experimental work, and for our purpose here, we take this to mean empirical data.
- *Claim.* An assertion from the data. In school science this is equivalent to the 'conclusion' which now seems rather misleading in that it implies arriving at a *final* accepted statement. In reality, pupils (and of course scientists themselves) can only make tentative claims. (A claim can also be a prediction from the data, as in the sequential steps in the diagnostic task described above.)

- *Warrant*. The reason, rules or principle for justifying the connection between the data and the claim. In terms of the jurisprudential analogy, Toulmin equates the warrant to 'the system of law' in some cases, and 'the current laws of planetary physics' in others (see pp. 95 *et. seq*. and p. 184 respectively) for instance. In the context of school science, we are talking about the range of tried and tested methods of valid experimentation (the 'case law' of procedural understanding, underpinned by our concepts of evidence), as well as the substantive laws and principles, the complex network of interlocking theories that constitute the accepted body of scientific knowledge.
- *Backings*. The *detailed* statements of fact upon which the warrant is based. In the case of the legal examples, the backings would encompass the *particular* 'statutes and provisions' on which the current laws are based. In our examples, it would be the *detailed* facts and ideas which underpin the data collection such as the number of readings taken, the method of averaging, the validity of the measurement itself and so on. Note here that backings differ from warrants in that the backings are the *precise* elements which relate to the claim in question, whilst the warrant is the complete set of ideas—in Toulmin's terms, the 'hypothetical bridging statements' and 'ways in which we can safely argue from the facts'.
- We have added a secondary backing term[5] to cater for the fact that, in our imaginary court proceedings, the experimenter is likely to be faced with a series of layers of justification. The first, and most proximate, should usually be a defence of the data itself. But after that, a sceptic might ask questions such as:
  - Is the experimenter competent?
  - Do these results agree with what other researchers have found?
  - Does it accord with the substantive knowledge in the area?
- *Qualifier*. A statement about the strength or 'force' of the claim'. This could include, for instance, statistical reasoning such as 'it is 95% likely that the claim follows from these data'.
- *Rebuttals*. Exceptions to the claim and/or conditions under which the claim will not be 'true'. For example, the results of a survey of plants in the UK should not be generalised to other countries with different climates.

Figure 6, based directly on that used extensively by Toulmin, depicts how these elements relate to each other.

The legal analogy itself, and the associated structure for the argument, suggest that in arriving at a claim from an experiment or analysing the claims of others:

- Any claim should be actively defended rather than passively evaluated.
- This active defence should clearly delineate the backings, qualifiers, rebuttals and warrants on which it rests.
- Claims in the press or media can be 'tried' by ascertaining the backings, qualifiers, rebuttals and warrants which have been used (or not) to judge the data upon which the claim is based.

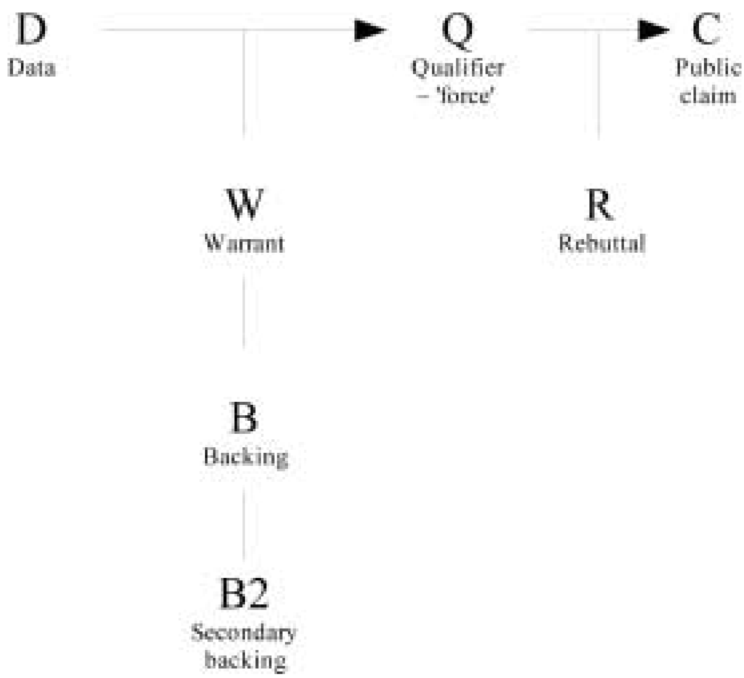

Figure 6. Toulmin's structure of argumentation

Can we link practical work and scientific literacy through argumentation?

In the sections that follow, we shall attempt to explore what elements of a science curriculum which uses the 'court of law' analogy as a teaching tool might look like. This would, of course, require testing in practice before we could advocate its adoption as anything other than an experiment. As we noted at the beginning of this article, the claim is the essential element which links school practical work and scientific literacy.

School science practical work teaches pupils to look forward, focusing on the 'data–claim' part of the Toulmin 'structure of argument' diagram, with perhaps some reference to other elements of the structure. The end point is the written account for the teacher, or for assessment purposes, culminating in a 'conclusion'. Any ensuing 'debate' or argumentation is likely to be conduced in terms of what went wrong. But we can envisage that argumentation which includes all of Toulmin's elements could be conducted by a class 'court' with the investigator being required to argue the merits of the data they have collected and their interpretation of it. For example, referring back to the three types of practical work, an extended period of fieldwork for post-16 students, at a field study centre perhaps, could culminate in groups being asked to justify their claims in a mock planning enquiry. They might then look at the real data from a planning enquiry concerning a similar issue and attempt to delve 'backwards' into it. Variants of this approach suitable to different ages and abilities are not difficult to imagine.

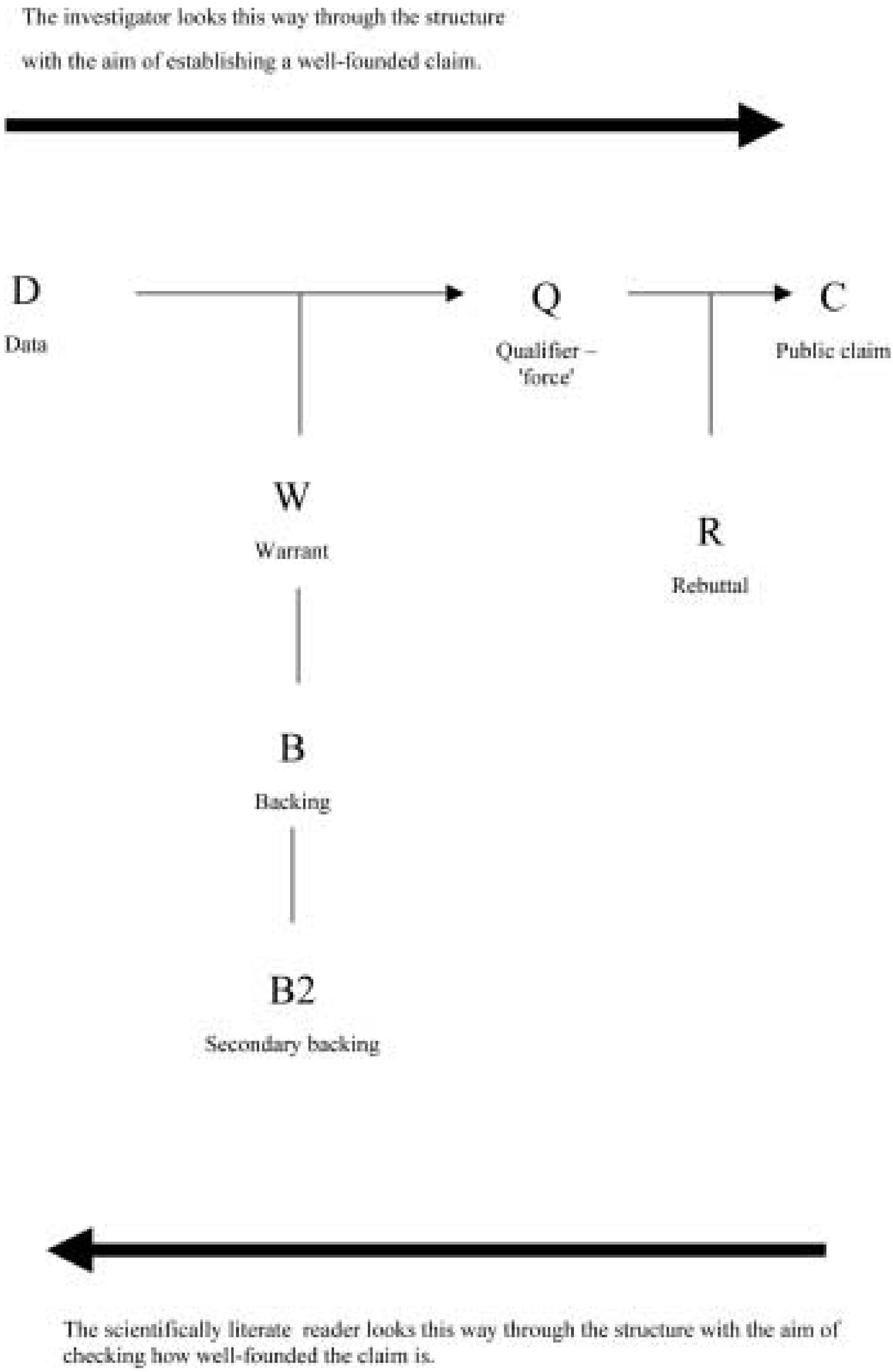

Figure 7. Toulmin and looking forward and looking back at the investigation process

An example of encouraging students to take part in such argumentation is reported by Kim and Song (2003) who gave groups of middle school students some open tasks. The students then constructed a report for peer review, after which each group was asked to argue the case for their claims through critical discussion. From their results, Kim and Song developed a model of argumentative scientific inquiry in which they suggest that practical work should be closely linked to argumentation: 'Argumentation gives feedback to the experiment activity. On the other hand, the experiment is the basis for argumentation' (p. 15).

In Israel, Zion *et al.* (2004) have developed a new open inquiry biology curriculum which promotes learning in a dynamic fashion including argumentation, making changes based on emerging data where appropriate.

Scientific literacy, on the other hand, requires the pupil to 'look back' (Figure 7) and is, of course, more complex, not least because the pupils have not designed the investigation(s) or collected the data themselves. We have already referred to the complexity of some big issues which make them virtually inaccessible to examination.

Much of the other literature on argumentation in relation to school science tends to present pupils with 'big ideas' such as the explanation of day and night, genetics, particle theory, or the pros and cons of zoos (see, for example, Zohar & Nemet, 2002; Erduran *et al.*, 2004).

Again these exercises are of value in relation to argumentation and scientific literacy but they tend not to rely on primary data, thus making it difficult, if not impossible, to question the warrants, qualifiers and backings that lie behind the claims.

One step down from these highly complex issues are smaller scientific literacy issues or issues which can be broken down into still smaller elements more accessible to pupils. We can envisage that examples of topical or local issues such as the safety of an incinerator (which we have explored in detail elsewhere Tytler *et al.*, 2001a, b) could yield data which would allow pupils to practise for themselves the analysis and interpretation of 'real' data. In this particular case, the claims were exposed publicly in a series of hearings and with the active engagement of the local press and community groups. The evidence unearthed included details of the measurement and sampling procedures, and local detective work rapidly uncovered the other layers in our structure, including bias, funding, political and economic issues. Presenting *all the data* would be too overwhelming for pupils, but we can envisage pupils engaging with *complete sets of data* about particular aspects of the issue so that they could understand, or even take part in or recreate, the debate.

In judging the strength of the claim, pupils would need to 'look back' at the primary backings for the data; how the data were collected, i.e., the experimental design, methods of measurement and empirical data collection. To do this, they have to understand that experimental design and empirical measurement are significant elements and need to be examined carefully. It is here that their own experience of collecting data comes into play. The structure of the argument they use to create and defend their own claims becomes the structure they use to examine the incinerator issue.

A way forward

A study of pupils' and parents' views (Osborne & Collins, 2000) found that pupils themselves want more practical work, extended investigations, contemporary science examples and opportunities for discussion. The study found that pupils found it hard to 'make the connection between school science and their everyday lives' (p. 6) and that parents believe that school science should include contemporary scientific issues.

A wider range of practical work would allow pupils more opportunity to 'look forward' and to create claims which they are required to defend. The shift in emphasis away from rather passive 'evaluation' to the more active idea of defending the data seems particularly useful since it is often the way that scientific ideas become accepted in actuality. Getting to grips with complex contemporary issues is bound to be a slow process and, we suggest, one which can only be accomplished in a staged way over a long period. A typology of such issues may be useful here, allowing us to locate some as being so complex that information and debate on ethical issues may be all that can be attempted. Others may fall into a 'too small to be seen as relevant' category. But there are intermediate issues which allow for genuine interaction with the argument.

The structure of argumentation with its elements may prove to be a useful link in helping pupils to bridge the gap between practical science in school and contemporary issues—more work will clearly be needed to establish effective teaching strategies. Here are some suggestions to begin the debate, some of which could be introduced in primary school whilst others could run beyond the 16-year-old age group:

1. Begin with simple lab-based practical investigations (practical work type 1, page 273, but more interesting examples than sagging bridges obviously exist!) with a view to establishing an understanding of the basic concepts of evidence and the structure of this kind of experimental design
2. Follow this up by asking pupils to defend their claims, introducing them to the structure of data, claim, backing, etc, as a support for them.[6]
3. Extend the range of investigations to include fieldwork (practical work type 2, page 273) where *post hoc* analysis is needed, and diagnostic tasks (practical work type 3, page 273) where steering an efficient and economic route through sequential tests is the key. This type of task is often of interest to pupils and will extend their understanding of experimental design into analysis of larger scale data and the difficulties of planning sequential and logically related tasks respectively.
4. The defence of claims now is more complicated as it requires the pupil not simply to defend the individual bits of data, or the design of a single task, but the reasons for choosing the data from the fieldwork data frame, or the quality and efficiency of the route they have plotted. The diagnostic tasks may be particularly useful here because pupils need to be sure of their claim in one subtask before choosing what to do next. The link to medical diagnosis may help to stimulate interest.

5. Move on to investigations which can be seen to be directly linked to a local issue, such as the incinerator issue referred to above. Fieldwork simulating the situation is quite easy to devise, and real data from the environmental dataset is to hand. The effect of bias can then be seen more clearly because the data is there to be inspected, and its potential misuse highlighted. Simulated planning enquiries (for instance) might follow.
6. Finally turn to the bigger issues where all the relevant data are not available. But now we hope that the pupil will have a structure through which to examine the claims and to understand why there might be differences of opinion. They will appreciate that data represent not ‘absolute truth’ but merely the best we can do at the time, and that alternative interpretations are quite possible.

We do not underestimate the problems that this kind of approach brings for science teachers, who have not traditionally been used to promoting classroom debate of this kind. Newton *et al.* (1999) showed that there was little opportunity for discussion in science classrooms and that any discourse around evidence tended to be teacher dominated. The Wellcome Trust’s report (2001), *Valuable lessons*, found that many science teachers ‘lack the skills, confidence and time to initiate and manage classroom discussion’ but that the majority of teachers believe that pupils should have the opportunity to explore issues related to biomedical science and ‘view this kind of exploration as vital to developing self confidence, developing lines of critical thinking and enabling students to deal with socio-scientific issues in a balanced way’ (p. 2).

In a study by Simon *et al.* (2006), teachers attended workshops to develop materials and strategies to support argumentation in secondary science classrooms. From this study, in-service materials have been developed. Similarly Colucci-Gray *et al.* (2006) explored the potential of role-play as a way of encouraging students to engage with scientific issues and of promoting dialogical and reflective learning.

How such approaches to practical work can be embedded into the existing curriculum is beyond the scope of this paper but what is obvious is that it will inevitably come into conflict with the constraining effect of the current assessment system in England and Wales, of which we (Gott & Duggan, 2002) and others (Leslie *et al.*, 2002) have written elsewhere. Suffice it to say that, if scientific literacy is a genuine goal, then a shift in emphasis in both the content of the practical science curriculum and its assessment is required.

Duschl (2000) presents a strong case for a shift in the science curriculum towards teaching science which more closely resembles ‘real’ science with an emphasis on argumentation. He writes that pupils should be held accountable for the quality of their results and that: ‘Claims and positions should be backed up with evidence, reasons and warrants’ (p. 203).

Duschl argues that it is only when this shift takes place that science education will change ‘from knowing what there is to know to learning and evaluating how we know and why we believe what we know’ (p. 205).

We suggest that widening the range of types of practical work and explicitly linking practical work and scientific literacy though argumentation using Toulmin's model may be a way forward.

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Notes

1. By 'fair test' investigations we refer to experiments where the independent variable is changed and, to test the effect of this change on the dependent variable, all other variables are controlled as far as is possible in what has become a routinised way (Gott & Duggan, 2002).
2. Project work is one such, but it can be seen as a collection of experimental (and other) tasks which more or less conform to one of these types.
3. *Observing and an observation.* We need to distinguish here how we have chosen to use the terms observing and observation. We take observing to be theory-driven. It is the act of looking at (or more generally sensing) an event though a particular (substantive) conceptual framework. A physicist observing the shape of low-profile tyres on a sporty car would see the structural rigidity inherent in their profile, etc. An observation, by contrast, we take to be the act of judging some qualitative event. So, the ammonia smell referred to in the above example is a measurement of its presence or absence and relies on experience in knowing what ammonia smells like as well as deciding whether the smell is strong enough to be counted as present. At that point, the measurement is made as present or absent (or 1 or 0).
4. Recent research on lab-based investigations with undergraduate students (Gott & Roberts, in press) suggests that approaches to design can be grouped as one of the following: (a) a 'linear' approach—a decision is made on the design at the beginning. The design is then adhered to, regardless of any problems that might arise; (b) a 'divergent' approach—a design which allows the investigator to collect any data which might, or might not, be relevant as s/he proceeds but one in which the focus is lost. This leads to problems with analysis when the student may become overwhelmed with the data; (c) an 'iterative' approach—the design is economical but flexible with the investigator modifying the design as problems emerge, repeating it with each modification and always keeping the task in mind.
5. It is not always the case that substantive ideas are 'secondary' of course—in designing an investigation they may well be at the forefront. But in defending a claim the quality of the data is the critical factor since, on rare occasions, its lack of consonance with established theory can constitute a scientific breakthrough.
6. This is akin to 'evaluation', but likely to be more attractive to pupils who will be familiar with the idea of the 'scientist in the courtroom' in the detective television series popular across the world.

References

Coderre, S., Mandin, H., Harasym, P. H. & Fick, G. H. (2003) Diagnostic reasoning strategies and diagnostic success, *Medical Education,* 37, 695–703.

Colucci-Gray, L., Camino, E., Barbiero, G. & Gray, D. (2006) From scientific literacy to sustainability literacy: an ecological framework for education, *Science Education,* 90(2), 227–252.

Department of Education and Science & The Welsh Office (1989) *Science in the national curriculum* (London, HMSO).

Duschl, R. (2000) Making the nature of science explicit, in: R. Millar, J. Leach & J. Osborne (Eds) *Improving science: the contribution of research* (Milton Keynes, Open University Press).

Erduran, S., Simon, S. & Osborne, J. (2004) TAPping into argumentation: developments in the application of Toulmin's Argument Pattern for studying science discourse, *Science Education,* 88, 915–933.

Gott, R. & Duggan, S. (2002) Problems with assessment of performance in practical science: which way now?, *Cambridge Journal of Education,* 32, 183–201.

Gott, R. & Duggan, S. (2003) *Understanding and using scientific evidence* (London, Sage).

Gott, R., Duggan, S. & Roberts, R. (2003) Concepts of evidence. Available online at: www.dur.ac.uk/richard.gott/Evidence/cofev.htm (accessed 30 August 2007).

House of Commons, Science and Technology Committee (2002) *Science education from 14 to 19. Third report* (London, House of Commons, Science and Technology Committee).

Kim, H. & Song, J. (2003) *Peer argumentation as an authentic feature of scientific enquiry in schools* (Melbourne, ASERA).

Lang, M., Drake, S. & Olson, J. (2006) Discourse and the new didactics of scientific literacy, *Journal of Curriculum Studies,* 38(2), 177–188.

Leslie, S., Keiler, L. & Woolnough, B. (2002) Practical work in school science: the dominance of assessment, *School Science Review,* 83(304), 83–88.

Newton, P., Driver, R. & Osborne, J. (1999) The place of argumentation in pedagogy of school science, *International Journal of Science Education,* 21, 553–576.

Nuffield Foundation (1966) *Nuffield chemistry: introduction and guide* (Harlow, Penguin).

Osborne, J. & Collins, S. (2000) *Pupils' and parents' views of the school science curriculum* (London, King's College).

QCA (2005) *GCSE criteria for science* (HMSO, London).

Roberts, R. & Gott, R. (2003) Assessment of biology investigations, *Journal of Biological Education,* 37(3), 114–121.

Royal Society (website) *'Nullius in verba'*. Available online at: http://www.royalsoc.ac.uk/page.asp?id=6186 (accessed 30 August 2007).

Simon, S., Sibel, E. & Osborne, J. (2006) Learning to teach argumentation: research and development in the science classroom, *International Journal of Science Education,* 28(2/3), 235–260.

Toulmin, S. E. (1958) *The uses of argument* (Cambridge, Cambridge University Press).

Tytler, R., Duggan, S. & Gott, R. (2001a) Dimensions of evidence, the public understanding of science and science education, *International Journal of Science Education,* 23, 815–832.

Tytler, R., Duggan, S. & Gott, R. (2001b) Public participation in an environmental dispute: implications for science education, *Public Understanding of Science,* 10, 343–364.

Wellcome Trust (2001) *Valuable lessons: Engaging with the social context of science in schools* (London, The Wellcome Trust).

Zion, M., Slezak, D., Shapira, E., Link, E., Bashan, M., Brumer, M., Orian, T., Nussinowitz, R., Court, D., Agrest, B., Medolovici, R. & Valanides, N. (2004) Dynamic, open inquiry in biology learning, *Science Education,* 88(5), 728–753.

Zohar, A. & Nemet, F. (2002) Fostering students' knowledge and argumentation skills through dilemmas in human genetics, *Journal of Research in Science Teaching,* 39, 36–62.