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The research reported in this paper stemmed from our conviction that argument is a central dimension of both science and science education. Our specific intention was to determine whether secondary science teachers in England give pupils opportunities to develop and rehearse the skills of argumentation during their lessons. We found that classroom discourse was largely teacher dominated and tended not to foster the reflective discussion of scientific issues. Opportunities for the social construction of knowledge, that are afforded by the use of argument-based pedagogical techniques, were few and far between. After a discussion of teachers' responses to this finding, we highlighted two major explanations: firstly, limitations in teachers' pedagogical repertoires; secondly, external pressures imposed upon science teachers in England by the National Curriculum and its assessment system.

Theoretical developments in perspectives on learning

We believe that argumentative practices are central both to education and science. Moreover, we believe that pedagogies which foster argument lie at the heart of an effective education in science. Our paper begins with an expansion of this position.

Over the last couple of decades, a major shift has been taking place in the way learning is viewed, away from seeing it as a process confined to the individual mind towards recognizing it as also involving social and cultural processes. Research undertaken from an anthropological perspective has highlighted the way in which learning is framed by social and institutional contexts, and is assisted by culturally produced artefacts (Lave 1988). Furthermore, studies undertaken from a socio-linguistic perspective indicate the way in which language plays a critically important role in learning, as it is through language that the cultural tools and 'ways of seeing' of a community are made available to learners (Vygotsky 1978, Lemke 1990, Wertsch 1991). As Lemke (1988: 81) has pointed out, 'the mastery of academic subjects is the mastery of their specialised pattern of language use'. From this socio-linguistic perspective, learning within a discipline requires adopting the norms of the language of that discipline. For young people learning science, this requires their participation, through talk and writing, in thinking through and making sense of the scientific events, experiments and explanations to which they are being introduced (Driver *et al.* 1994). Active participation by learners

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in the discourse of lessons is therefore central to providing an enabling learning environment. Talking offers an opportunity for conjecture, argument and challenge. In talking, learners will articulate reasons for supporting particular conceptual understandings and attempt to justify their views. Others will challenge, express doubts and present alternatives, so that a clearer conceptual understanding will emerge. In such a manner, knowledge is co-constructed by the group as the group interaction enables the emergence of an understanding whose whole is more than the sum of the individual contributions. The extent to which such a learning environment is provided in secondary science lessons is the focus of the empirical study which is reported later in this paper.

What is argument?

A particularly valuable way of looking at science classroom discourse is in terms of argument. Krummheuer (1995: 231) provides a helpful definition of argument as 'the intentional explication of the reasoning of a solution during its development or after it'. In some cases, this 'explication of reasoning' will be in terms of a single line of thought: this is often referred to as *monological argument*. In other cases, particularly where a number of people are involved in the reasoning process, there will be a number of contrasting lines developed: this is often referred to as *dialogical argument*. Although we occasionally draw a further subtle distinction between 'argument' and 'discussion' – proposing that 'argument' is the sub-set of 'discussion' which is focused upon the resolution of a specific controversy – we have used the terms relatively synonymously in the present paper.

Toulmin (1958) developed a model of argument that has been drawn upon by educators, and science educators in particular, to identify the components and complexities of students' arguments (e.g. Krummheuer 1995, Druker *et al.* 1996, Jiménez-Aleixandre *et al.* 1997). He identified four main types of statements which contribute to an argument: *claims*, assertions or conclusions whose merits are to be established; *grounds* or data which are the facts that are appealed to in support of the claim; *warrants* which are the reasons justifying the connection between particular data and the knowledge claim; and finally, *backings* which are basic assumptions that provide the justification for particular warrants. We find this to be a useful structural account of argument, although one that needs to be supplemented by a social psychological account when 'real-life' arguments are being analysed (e.g. Richmond and Shriley 1996, Alexopoulou and Driver 1997).

Since Toulmin's seminal work (1958), it has become increasingly apparent that what counts as 'a good argument' is relative to the context in which it takes place: the validity of an argument is a matter of 'informal' rather than 'formal' logic and different areas of human activity (e.g. legal systems, evangelical meetings, domestic interactions, etc.) will have their own distinctive forms of argumentation. Putting it simply: different communities address different types of issues and are satisfied by different kinds of solutions. Forms of argumentation that are typically valued by the scientific community include: the development of simplifications, e.g. taxonomies, laws and mathematical formulae; the postulation of causal-explanatory theories which generate novel predictions; the presentation of evidence from observation and experiment, etc.

It is interesting to note the convergence between recent advances in educational theory (inspired by socio-cultural models of learning) and advances in the field of argumentation (inspired by the work of Toulmin). In both cases, the centrality of the community of practice has been emphasized: the community of practice is ultimately 'the measure of all things', and learning 'the measure of all things' requires active participation within that community.

The place of argument in science and science education

Argument in science

The importance of argument in science can be illustrated on a number of levels. Firstly, argument is central to the philosophy of science. There has been a general trend over the last half century away from the view that science is predominantly an empirical process, where claims to truth are grounded in observation and where conclusions are seen as unproblematic deductions from those observations. The shift in position has been towards a view of science as a social process of knowledge construction which involves conjecture. This perspective recognizes that observations are theory laden (Hanson 1958, Kuhn 1962) and, therefore, that it is impossible to ground claims for truth in observation alone. Instead, claims are seen to be grounded through processes of argumentation, where the function of argument is to construct plausible links between the imaginative conjectures of scientists and the available evidence. Moreover, the notion of 'evidence' itself is open to scrutiny, both in terms of the way that it is framed conceptually and in terms of the trust that can be placed in its reliability. The key activity of science, therefore, is the evaluation of conjecture in the light of available evidence; the *raison d'être* of the scientist is to determine which conjectures present the most convincing explanations for particular phenomena in the world.

At an institutional level, argument is manifest in the establishment of scientific knowledge. Science is the product of a community and new scientific conjectures do not become public knowledge until they have been checked, and generally accepted, by the various institutions of science. Thus, papers are reviewed by peers before being published in journals; claims made in published papers are scrutinized and criticized by peers; sometimes experiments are repeated and checked; alternative interpretations are put forward and debated. The rational processes of argument are the foundation of these institutionalized practices. However, it should always be remembered that – even in science – argument is not a purely objective and unproblematic activity. Scientists are humans, after all, and are influenced by factors, e.g. social commitments and personal values, as well as by the wider culture of ideas and technological capabilities evident in society at any one time.

Through this discussion of science as the production of socially constructed knowledge, we have indicated that the argumentative practices of the scientific community are pivotal in the establishment of knowledge claims. Observation and experiment are not the bedrock upon which science is built; rather they are handmaidens to the rational activity of constituting knowledge claims through argument. It is on the apparent strength of arguments that scientists judge competing knowledge claims and work out whether to accept or reject them.

Argument in the learning of science

As we commented earlier, learning science involves becoming socialized into the languages and practices of the scientific community. It is necessary for students to develop an appreciation for both the kinds of questions, and the types of answers, that scientists value. Moreover, to become scientists, they must make these forms of argument their own. This process of enculturation into science comes about in a very similar way to the manner in which a foreign language is learned, i.e. through use. It is not enough for students just to hear explanations from experts (e.g. teachers, books, films, computers); they also need to practise using the ideas for themselves. 'The' answers to 'the' questions need to become 'their' answers to 'their' questions. Through practice in posing and answering scientific questions, students become active participants in the community of science rather than just passive observers.

Furthermore, through taking part in activities that require them to argue the basis on which knowledge claims are made, students also begin to gain an insight into the epistemological foundations of science itself.

Over the last few decades, there have been various studies undertaken which have highlighted the importance of talk in enabling students to develop their understandings of scientific ideas. Seminal work was undertaken by Barnes (1977), and Barnes and Todd (1977). More recently, Lemke (1990) and Sutton (1992) have extended our understanding of the significance of language in science and our appreciation of the centrality of linguistic practices for the induction of students into science. Ways of achieving this end have been explored in science classrooms across the world. The rise of constructivist learning approaches – which have stressed the importance of active participation by learners for making meanings – has led to frequent calls for discussion and group work to be given higher priority in science lessons (e.g. CLIS 1987, Driver 1987, Duit *et al.* 1991). The literature on constructivist teaching continues to be an important source of information about appropriate strategies for promoting discussion and argument in order to develop students' conceptual understandings.

Finally, we would argue that science education also has an important contribution to make to the general education of students by developing their ability to understand, construct and evaluate arguments (both as individuals and as contributors to a group). The discussion of socio-scientific issues (whether or not to eat meat; how domestic waste should be disposed of; the ethics of the new genetics, etc.) give students opportunities in lessons to consider relevant evidence, develop appropriate arguments and come to reasoned conclusions about issues that impinge directly upon their own lives.

Traditionally, science teaching has paid little attention to argument and controversy. This has given a false impression of science as the unproblematic collation of facts about the world, thereby rendering disputes between scientists, whether historical or contemporary, puzzling events (Geddis 1991, Driver *et al.* 1996). It has also failed to empower students with the ability to argue scientifically through the kinds of socio-scientific issues that they are increasingly having to face in their everyday lives (Solomon 1991, Norris and Phillips 1994). If pupils are genuinely to understand scientific practice, and if they are to become equipped with the ability to think scientifically through everyday issues, then argumentative practices will need to be a prominent feature of their education in science.

Empirical evidence

To provide a foundation for future research projects concerning argumentation in secondary science lessons, we decided to collect information on the extent to which teachers currently provide opportunities for pupils to contribute to the co-construction of knowledge through discussion and argument. To obtain information about the frequency of such activities, we devised an observation schedule which characterized the range of activities that take place in secondary school science lessons from Year 7 (age 11) to Year 11 (age 15). This descriptive instrument was intended to provide us with tentative answers to two key questions:

(i) How is the National Curriculum in science being implemented in England?
(ii) What opportunities are being given for discussion, argumentation and the social construction of knowledge?

Design of the observation schedule

After reviewing existing classroom observation instruments, we decided that none was appropriate for our particular purposes. We therefore developed an instrument that was oriented to the following concerns.

(i) To focus upon the activities being conducted by pupils.
(ii) To focus upon how pupils are grouped for carrying out their activities.
(iii) To capture the forms of interaction between teacher and pupils.

The schedule that we devised, shown in figure 1, was intended to capture what pupils were doing in lessons at regular intervals of time (we used 30 s as the coding interval). The final form of the schedule was the result of a developmental process:

SCHOOL____________________ TEACHER____________________ CLASS__________

TITLE_____________________ DATE______________________ TIME__________

		2	4	6	8	10	....	60
	whole class activity							
PWG	small group activity							
	individual activity							
	other							
	listening							
	reading							
	set exercises							
	copying							
	open pencil+paper tasks							
PA	observing a demonstration							
	conducting closed practical work							
	closed practical work							
	conducting open practical work							
	preparing or clearing away							
	a formal group discussion							
	other							
	instructions from the teacher							
	explanation of a scientific idea by teacher							
P&TI	qustion-answer interactions							
	deliberative interactions							
	other							
	pupil-generated questions							

Figure 1. The observation schedule.

initial forms were used in a range of lessons and successive modifications were made so as better to represent the variety of activities observed and to allow the coding of activities to be undertaken as unambiguously as possible.

There are three sections to the schedule, the first of which is devoted to the basic unit of analysis: the *Pupil Activity (PA)*. Entries in this section capture the main types of activity in which pupils are engaged during their science lessons. The 11 types of activity covered by the schedule are presented and explained in Appendix A. There are two further sections: *Pupil Working Group (PWG)*, which allows a record to be kept of how pupils are grouped; and *Pupil and Teacher Interactions (P&TI)*, which is designed to capture the nature of verbal interactions that are occurring (if any) between the teacher and pupils. Again, the explication of the different types of groupings and the different forms of pupil and teacher interactions are presented and explained in Appendix A.

Our schedule enabled us to give a general account of the time spent on different kinds of science lesson activities. However, our focus on opportunities for discussion, argumentation and the social construction of knowledge meant that we were particularly interested in activities, e.g.:

(i) open writing tasks (individually or in small groups);
(ii) conducting open practical work;
(iii) formal group discussion tasks;
(iv) pupil and teacher deliberative interactions.

Using the observation schedule

Scoring the schedule involves placing a mark against the type of *PA* and *PWG* that predominates during each 30 s interval (i.e. a mark in one box, in each of the two sections, in each column); the marked boxes should represent the 'most appropriate summary' of the activities taking place during each 30 s period. Underlying the coding system is the idea that the categories within both the *PA* and *PWG* sections are discrete and (when the category 'other' is included) exhaust the range of possible science lesson activities and groupings. Thus, at any one point in time, a pupil would be engaged in only one of the types of activities and would be involved in only one type of grouping. Further, it is assumed that the events observed are relatively enduring and discrete. In order to prevent the schedule from becoming unmanageable, we decided not to record events which deviated from this pattern (e.g. if a teacher were very briefly to interrupt a small group activity to give a short instruction). Thus for each 30 s interval, only one mark is made in the *PA* section and one mark in the *PWG* section.

When all the students in a science lesson are engaged in the same activity (e.g. listening to the teacher, observing a demonstration, etc.), then this activity can be coded unambiguously for the given time interval. There are times in science lessons, however, when pupils are not all doing the same thing and this creates a problem for scoring the schedule. In order to avoid this problem, we selected one pupil at random from each class (the *Pupil Representative*) and coded only the activities of that pupil. In making this decision, we assumed that the activity of our *Pupil Representative* would generally be a satisfactory representation of the activity of the class as a whole.

Coding for the section *P&TI* is basically the same as for *PA* and *PWG*, though there are some important differences. Most significantly, there is no expectation that one box will be marked every 30s. A box in the *P&TI* section is marked only if an interaction is observed for a substantial proportion of the 30s period (e.g. over half). When the teacher is interacting with pupils, the categories within the *P&TI* section serve to elaborate the pupil activity (usually 'listening'). When pupils are working in groups or on their own activities, it is usual that the teacher is circulating around the class interacting with pupils as necessary. In such a situation, attention is given to the *Pupil Representative*, and only those interactions between the teacher and the *Pupil Representative*, or the *Pupil Representative's* group, are coded. (*Pupil and Pupil Interactions* – discursive interactions in which the teacher was not involved – were not specifically recorded. In fact, relatively few of the *Pupil and Pupil Interactions* that were observed appeared to be 'on task'.)

Finally, in order to contextualize the schedule's results, brief notes relating to the lesson activities are recorded at the bottom of the observation sheet. We found that placing footnotes below relevant 30-s-interval columns was particularly useful, especially when 'other' was recorded.

Sample of lessons observed

Ideally, we would have liked our sample to have been drawn from schools all over England. However, for pragmatic reasons, we had to limit our study to schools in the London area. In order to obtain a sample that would be as representative as possible, we decided to avoid the exceptional and to select from mixed-sex comprehensive schools with an average school-level achievement profile (as determined from the 1996 'school league' tables). We wrote to schools asking whether they would be prepared to take part in the study, explaining that we were interested in describing the activities which are typically carried out in science lessons. We asked to observe lessons with 'average' children as far as possible, to observe lessons following a balanced science course, and not to observe revision lessons. Once a school had agreed to participate, arrangements were made with the Head of Science for a date to visit when a range of Year 7–Year 11 lessons could be observed.

Seven schools participated in the study from a range of Local Education Authorities in the London area. In all, 34 lessons were observed: 11 from Year 7; 11 from Years 8 and 9; and 12 from Years 10 and 11. The predominant subject orientations of the lessons are given in table 1 below. All the classes were following general science or balanced science courses; revision lessons were not observed; the number of non-mixed ability classes was not high (three lower ability, five higher ability). Finally, the mean length of each lesson observation was 52 min (range: 34.0–95.5 min).

The conduct of the school visits

The visits were carried out during the second half of the 1996–1997 school year. The majority of the lessons ($n = 30$) was observed by PN, and a minority ($n = 4$) was observed by RD. A number of lessons was jointly observed by PN and a research assistant in order to obtain a measure of the reliability of the coding. A brief account of this reliability study is given in Appendix B.

Table 1. The frequency of different science subjects observed.

	Biology	*Chemistry*	*Physics*	*Earth Sci.*	*Total*
Year 7	1	4	6	0	11
Years 8 and 9	3	2	5	1	11
Years 10 and 11	5	2	3	2	12
Total	9	8	14	3	34

In addition to observing the lessons, opportunities were taken towards the end of each day's visit to discuss the emerging findings of the project with the Head of Department. In these discussions, we focused on the apparent lack of use being made by science teachers of group discussion and asked for views as to why this may be the case. These interviews were tape-recorded and transcribed. We also held similar discussions at two out-of-school meetings with Heads of Science Departments and other experienced science teachers. The outcomes of these discussions are reported later in the paper, and we use the teachers' comments in the interpretation of our findings.

Findings that emerged using the observation schedule

In all but a small number of cases, the lessons we observed focused on a specific subject area and included a range of activities for the pupils. Lessons generally began with the teacher introducing a topic to the class, rehearsing previous work on this topic, and outlining an activity to be undertaken. Pupils would then undertake the specified activity (which could include practical work, exercises from books, other writing or drawing tasks, use of computer programmes, etc.). Finally, the lessons tended to be brought to a close with a period of clearing up, in some cases discussion of the activities, and the setting of homework. We observed two lessons which departed significantly from this pattern. In one case, the teacher had provided a range of activities on graphing skills that included some computer-based exercises around which pupils were rotating. In the second case, the teacher had set the pupils a library research project to complete in groups over a period of several lessons. We therefore observed groups of pupils engaged in assorted reading and writing tasks, and using CD-ROMS for reference purposes.

Although each lesson tended to provide a range of activities for pupils, it was possible to construct an activity-based typology into which each of the 34 lessons could be placed. The two main groups of lesson types were those that involved pupil practical work and those that did not. Within these two main groups, we categorized lessons into one of 10 types. The numbers of lessons of each type for each age are given in table 2 below.

As the data in table 2 show, over two-thirds of the lessons involved practical work, and the most common lesson type $(n = 14)$ was the closed practical. In these lessons, the pupils tended to work in groups undertaking the same task. Some practical lessons were organized so that pupils cycled around a 'circus' of activities $(n = 3)$. Other practical lessons $(n = 4)$ were devoted to open investigations designed to fulfil the requirements of the National Curriculum (Sc 1). In addition, two practical lessons involved construction projects where pupils made artefacts

Table 2. The frequency of lesson types by practical orientation.

	Year 7	*Years 8 and 9*	*Years 10 and 11*	*Total*
Practical lessons				
Closed practical	5	5	4	14
Construction project	1	1	0	2
Circus practical	1	0	1	2
Practical exercise	0	1	0	1
Open investigation (Sc 1)	1	1	2	4
Non-practical lessons				
Teacher presentation	1	1	2	4
Text-based lesson	1	0	2	3
Computer-based activity	1	0	0	1
Library research project	0	1	0	1
No predominant activity	0	1	1	2
Total	11	11	12	34

(e.g. a periscope), while a final lesson was classed as a practical exercise (building electrical circuits from drawings of circuit diagrams) because it seemed to lack the creative/investigative component apparent in other practical lessons.

Non-practical lessons included: those consisting mainly of a teacher presentation ($n = 4$); text-based lessons ($n = 3$); a lesson focusing on a computer-based activity; and a lesson which was part of a group library-based project. In two further lessons, no one activity obviously predominated. It was notable that none of the lessons, neither practical nor non-practical, gave a major place to group discussion of problem-solving tasks, nor to less traditional activities, e.g. role play, simulations or debates.

We divided the lessons into practical and non-practical because the patterns of time usage differed markedly between the two groupings. Table 3 displays the average percentages of time spent in each *Pupil Activity* and in each form of *Pupil and Teacher Interaction*. The same information is displayed graphically in figure 2. The large standard deviations indicate the variation between lessons in the patterns of time usage, and this means that care must be taken in interpreting the results. However, key differences between lesson types are still evident. (The data are aggregated across all types of *Pupil Working Group*.)

The mean percentages displayed in the *PA* rows of table 3 indicate that the major proportion of pupils' time was spent 'listening' (31% practical, 44% non-practical), while very little time was spent 'reading' (less than 2% for both) or in 'group discussion' (less than 2% for both).

In practical lessons, far more time was spent in 'closed' (23%) as opposed to 'open' (8%), investigations. However, this difference was a consequence of there being a smaller number of open practical lessons; in fact, when open practical activities were carried out, they tended to take longer than closed practical activities. The time spent on 'open paper and pencil tasks' in practical lessons was accounted for mainly by pupils writing up the results of their practical activities. (We deemed this to be an open-ended activity as it required pupils to describe what they had done in their own words and to interpret their results.) The other time-consuming activity in practical lessons was 'preparing or clearing away' (11%). Very little time (0.4%, in fact, which was rounded to 0% in the table) was

Table 3. The proportion of total lesson time devoted to each activity.

	Practical lessons ($n = 23$)			Non-practical lessons ($n = 11$)		
Activity	*Mean %*	*Median %*	*SD*	*Mean %*	*Median %*	*SD*
Listening	31	23	16	44	42	26
Reading	0	0	1	2	0	3
Set exercise	2	0	7	21	10	29
Copying	7	0	12	11	1	17
Open paper and pencil task	17	13	17	13	0	27
Observing demonstration	1	0	2	3	0	5
Closed practical task	23	24	18	0	0	0
Open practical task	8	0	17	0	0	0
Preparing or clearing away	11	9	11	1	0	1
Group discussion	0	0	2	2	0	5
Other	1	0	3	4	0	11
Teacher giving instructions	18	15	12	15	16	8
Teacher explaining science	6	6	5	17	13	21
Question–answer interactions	8	9	5	13	14	7
Deliberative interactions	2	0	3	1	0	2
Other	0	0	1	0	0	0
Time observing lesson (min)	53	52	13	52	52	6

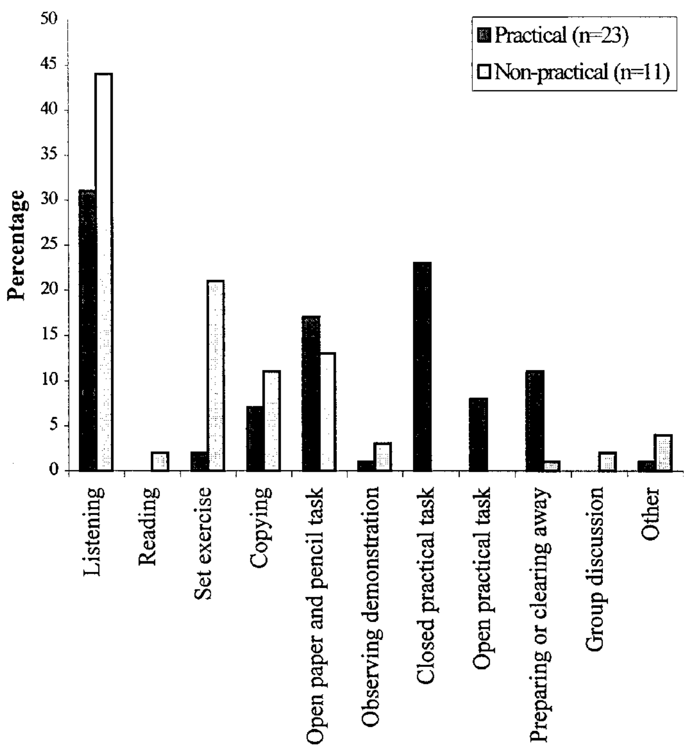

Figure 2. The mean percentage of lesson time devoted to different activities.

spent on 'group discussion' in practical lessons. This figure was entirely due to one lesson in which the teacher intercepted the practical work and asked the class to discuss, in groups, what makes a good conclusion and to give feedback to the class. Finally, our observations of pupils while they undertook their practical activities revealed that conversation focused predominantly on the technical aspects of completing the task. Little, if any, time was spent discussing the scientific ideas behind the practical work or the interpretation of the findings.

As previously noted, 'listening' was the dominant pupil activity in non-practical lessons (44%). Performing 'set exercises' and 'copying' together constituted a further third (32%) of the class time, nearly three times as much as was spent on 'open pencil and paper tasks' (13%). 'Group discussion' was notable by its absence: only one non-practical lesson included any such tasks, and this was a brief 5 min, activity in which pupils were asked to work in groups to review what they already knew about a topic.

The proportion of total lesson time that teachers spent in different forms of *P&TI* is also presented in table 3. In both the practical and non-practical lessons, teacher exposition dominated the interactions, with the teachers tending either to be giving instructions or providing explanations (which averaged out at 24% of lesson time for practical classes and 32% for non-practical classes).

Pupils were more actively involved in the interactions during question and answer sequences (which averaged out at 8% of lesson time for practical classes and 13% for non-practical classes). This form of interaction, described in the American literature as 'recitation', follows a well-defined pattern in which teachers ask a question (Q), which is followed by a pupil response (R), which is then evaluated by the teacher (E). This triplet, QRE, continues under the direction of the teacher in order to develop and rehearse points which the teacher deems important. The teachers' questions are not 'genuine' in the sense that they are not seeking to discover how pupils are reflecting upon the issues addressed. Rather, teachers are performing a 'checking routine' – their intention is to determine whether or not the pupils can reproduce the answers that they have in mind. The task for the pupil who responds is to recognize what it is that the teacher requires as an answer.

The form of interaction, which is ubiquitous in school lessons, differs significantly from that which we intended to capture with the category 'deliberative interactions'. In these interactions, teachers may ask ostensibly similar questions, but they are genuinely interested in how the pupils are reflecting upon the issues and typically encourage the pupils to give deeper elaborations of their reasoning. Rather than 'quick fire' questions and answers, the length of each contribution tends to be more extended. Different answers to the same question are often considered and compared. Also, pupils themselves contribute questions in the interaction. The general purpose of the interaction is to help pupils to reflect on the reasoning behind a particular issue and to encourage pupils to think through the issue for themselves. As can be seen from table 3, this form of interaction was not common in the science lessons that we observed (it averaged out at around 2% of total lesson time).

Since this study was based on a relatively small sample of lessons from one region of the country (and, as we have already noted, the variations in time usage between the lessons were not small), we have to exercise a degree of caution in generalizing from the data. This is particularly true when making comparisons between the three year groupings. However, there were some trends in the way that time usage appeared to change over the secondary years. There appeared to be a diminution, with age, in the time devoted to 'open ended paper and pencil tasks', with Year 10/11 pupils spending less than half the mean proportion of time that Year 7 pupils spent on such activities. In contrast, the mean proportion of time spent by Year 10/11 pupils on 'set exercises' and 'copying' was greater than for the younger pupils.

In summary, it seemed that science lessons were teacher dominated, with a heavy emphasis on teacher exposition and recitation forms of question and answer interaction. Written tasks tended to be closed in nature, involving copying or set exercises (and it may be significant that this trend appeared to increase over the secondary years). Practical work, especially open-ended practical work, provided the main opportunity for pupils to think for themselves during science lessons.

In conclusion, this study indicated that the dominant practices in secondary school science lessons tended not to include activities that support discussion, argumentation and the social construction of knowledge. Teachers' reasons for this are documented in the next section.

Teachers' views on argumentation in science lessons

In order to throw more light on the reasons why discussions were such a minor feature of pupils' experience, either in whole class or small group settings, two focus group interviews with a total of 14 experienced science teachers, some of whom were Heads of Department, were conducted. In addition, these were supplemented by five individual interviews. All the interviews were transcribed and then coded for recurrent themes. There is no suggestion that the findings from these interviews are representative, rather that they provide an initial insight into four factors which constrain or limit discussions, and lastly, some of the ways in which discussion in school science classrooms might be promoted.

Time constraints and the National Curriculum

The main reason which was mentioned by all participants was the problem of time.

> Time is a major problem and there certainly is a large contingent of teachers who see discussion as a luxury that can be dispensed with.

> The average teacher will not want to run discussion groups, the main reason is time.

In many cases, teachers commented that the National Curriculum, with its heavy content load, had exacerbated the problem of finding time for discussion.

> What has happened is that the National Curriculum has forced us down the road of 'we've got to get everything done' and so we have lost that feeling of luxury of time, cos we have to get through things and we are even struggling to get through the investigative work that we have to do.

> We use discussion infrequently because . . . the pressure of the curriculum really, we've got to get the content across most of the time.

> Discussion is slowly being pushed out of the curriculum because of time constraints.

> I think the National Curriculum keeps us from doing a lot of this because we have to push on and its a lot to recap a class discussion that lasts a lot of time.

Parents' concerns about their children's progress through the National Curriculum were also mentioned as a factor.

> One of the problems is that parents want to be sure that their children are learning and if kids come home with nothing in their books they want to know why.

The difficulties of managing discussion

Teachers were also clear that managing discussion effectively is a difficult pedagogical task.

> Many things can go wrong that you are not expecting, putting wrong children together, having wrong seating arrangements.
>
> Discipline is a major issue, it is very easy for a discussion to degenerate.
>
> Kids need to have information to be able to discuss the pros and cons of an argument.
>
> It is quite difficult to get full motivation, to get everyone taking part – it has to be an issue or a problem (in which they) have an interest.
>
> The main thing is that pupils are deeply interested in the problem.

Teachers also recognized that the published materials that they used were not helpful in supporting discussion activities.

> We rely on published materials and so although books say 'now discuss' the kids just don't discuss it. Or the teacher can say 'I want you to discuss the answers with one another' . . . the odd little argument can go on then, but that is not really what it is about.

Teachers' skills and views of science

Teachers in our interviews were clear that, because of the difficulty of using discussion in teaching, many teachers (usually but not always the less experienced) did not have the necessary pedagogical skills or the confidence that comes with them.

> We do have average and below average teachers who actually don't have the skills to run discussion groups. I think that it is quite a high level skill for teachers.
>
> Much depends on whether the teacher feels confident enough to take off on a tangent if the need arises, particularly if this means the exclusion of covering other content areas.
>
> Teachers need to be confident enough to accept that they may not know the answers, this may . . . discourage some teachers from allowing the situation to occur in the first place.

The epistemological orientation of science teachers was also commented on as a reason for not using discussion.

> If they are scientists who believe in black and white and firm answers they may not see the significance of discussion.

Even the experienced science teachers we talked with admitted to feeling unskilled at organizing and leading effective group discussions. All of them commented that they had had problems from time to time with discussion activities. There were a number of comments about the need for more training in the skills required to manage discussions and the importance of initial teacher training was underlined.

> Where are teachers meant to know about the possibility of doing this sort of thing if they don't pick it up during their teacher training?

Pupils' views of learning science

Teachers commented that pupils hold views about what activities are and are not appropriate in science lessons.

> Many children are not happy when they don't fill their course books up.

> The children are often not used to discussion during science lessons – while they might be quite happy doing so in an English lesson.

> Teachers in English classes do not have the same kind of problem in running discussions – perhaps because they have been trained to do it. Also the students actually see discussion as part of English and therefore seem happy to engage in it, but not in science.

These accounts indicated the recognition of both internal and external factors which affect the use of discussion and argument in science lessons. The internal factors related to the teachers' pedagogical skills, pupils' views and, to a lesser extent, to available materials. External factors concerned the pressure of time that teachers experience in 'covering' the National Curriculum.

Promoting discussion in classrooms

The data from the interviews would suggest that the development of discussion within school science is dependent on four constraints – advanced planning, appropriate time slots, a prerequisite knowledge base, and establishment of clear procedures for running group discussions. For instance, teachers commented:

> I think if we are going to carry out these kind of activities, I think basically kids need quite a bit of time to prepare in advance, maybe not in class time but maybe at home, to bring in information and so that they can argue certain points. I mean, I think what makes it difficult is students together in the classroom unprepared.

Existing resources, particularly SATIS (ASE 1986) were criticized for being too 'time consuming', whereas spending 'three or four minutes coming up with ideas' and then moving on should be one way of developing its use. Teachers were also aware that 'this isn't the kind of thing you can drop out of nowhere' and that the first few times might result 'in a complete pig's ear'. In short, the need for children to be prepared and prepare themselves was emphasized as indicated by the following comment.

> And it starts with kids being able to express anything, and not necessarily being able to argue well, but to express themselves well, what they have learnt and openly. And that comes first I feel. I mean, before you argue, you have to have a sound basis of what you understand. And I think the most important thing is for students to get up and just talk about their science – and that may be the first step.

Discussion in science was problematic because school science predominantly deals in ideas which are perceived to be right or wrong, whereas good discussion requires the participants to propose thoughts that are half-formed or simply flawed. Therefore, teachers need to 'impress on them that it doesn't matter if what they think is wrong'. Furthermore, groups may encourage careful initial selection and monitoring to ensure successful interaction – both of which are recommendations highlighted by Bulman (1985) and Dillon (1994), and not reinforced by the published materials. For as one teacher commented:

> Although the books say 'Now discuss bla, bla, bla . . . ' the kids don't now discuss it, well they may discuss it to some extent but . . . and the old little argument can then go on but that's not really what it's about . . . So probably because this isn't tackled in the published materials then people are not doing it.

Summary and interpretation

The results of our observation study, in keeping with many international studies, indicated that secondary science classrooms are strongly teacher directed. Very few opportunities are given for pupils to contribute to the process of constructing knowledge in lessons, and the utilization of small groups, or whole class discussion (concerning the interpretation of events, experiments or social issues) appears to be very infrequent.

In the 34 lessons that we observed, there were only two cases where the teacher set a group discussion task, and even these discussions lasted less than 10min each. The primary activity in the classrooms tended to be teacher talk. This was dominated by exposition and teacher-led question and answer interactions. Fewer than half of the lessons we perceived included some deliberative interaction between the teacher and the pupils; moreover, when this did take place, it occupied no more than 5% of the lesson time. Where opportunities were given for pupils to work in groups, e.g. on practical tasks, these were rarely organized in such a way as to encourage substantive discussion of the science involved. Instead, pupil talk focused on procedural aspects of the practical work. In the few cases where the teacher did give pupils opportunities for discussion, little guidance was given on how to organize these interactions, and the pupils observed did experience difficulties in managing the interpersonal dimensions.

We also interviewed the teachers about the range of teaching strategies they used and asked for their comments on the use of deliberative discussion. Generally speaking, the teachers did see the value of discussion for pupils' learning. However, they also acknowledged that managing discussion effectively is challenging and that they have few strategies for structuring discussion work, either in small groups or in whole class settings. Finally, the time pressure imposed by the need to 'cover' the National Curriculum was seen as a powerful factor militating against the greater involvement of pupils in the co-construction of knowledge through whole class and group discussion.

The relationship between educational theory and practice

At this point, we consider three different models of teaching and learning, and reflect on how these relate to the results from our study. The models we will consider are the *transmission* model, the *discovery* model and the *social constructivist* model. In figure 3 below, we characterize each of these models along a number of dimensions.

	Transmission model	*Discovery Model*	*Serial Constructivist Model*
Nature of science (for students)	Science as a fixed body of facts primarily accessed through authoritative sources (e.g. teacher).	Science as a body of facts, laws and theories primarily accessed through personal experience.	Science as plausible explanations for phenomena primarily accessed through argument.
Method of learning science	Paying attention to authoritative sources in order to acquire scientific knowledge from them via *absorption*	Paying attention to personal observations in order to draw general scientific principles from them via *induction*.	Collaborating (with authoritative sources) to arrive at convincing scientific explanations via the co-construction of knowledge.
Teaching approaches	Telling pupils the facts of science.	Organizing practical activities that will furnish pupils with appropriate observations from which appropriate conclusions may be drawn.	Negotiating experiences and explanations with pupils to persuade them of the value of accepted scientific ideas.

Figure 3. Models of teaching and learning science.

In the light of evidence from our observation study, we now consider which of these models of teaching and learning are reflected in teachers' pedagogical practices. We do not envisage these models as explicit theoretical frameworks that are held by teachers and that direct their method of teaching. Science teachers are rarely explicit about theories which guide their practice and, indeed, are often cynical about the value of such theories. Instead, we see the models as characterizing underlying features of sets of pedagogical practices; they are more descriptive of what teachers *do* than of what they *think*.

The social constructivist model strongly recommends opportunities for reflective interaction (e.g. through discussion and argument) to support the co-construction of knowledge. As we have noted, few opportunities were given in lessons for activities where this can take place. An exception was open-ended practical work which did provide opportunities for the personal and social construction of knowledge. The extent to which this can actually take place depends on the degree of openness of the task and the extent to which pupils are encouraged to reflect and negotiate interpretations of their findings. In general, apart from the limited evidence of open-ended practical work, there appeared to be little indication of a social constructivist perspective on science teaching being put into practice.

There was more evidence of teachers being guided by a discovery model. The fact that the majority of lessons included some pupil practical work indicates the value that teachers place on giving pupils first hand experiences. However, a closer inspection of the way the closed practical activities were conducted shows that they gave little opportunity for pupils to reflect and make their own generalizations. In fact, the practical activities tended to serve as illustrations of principles which the teacher wished to promote, thus reflecting more of a transmission view. Open-ended investigations, on the other hand, did provide opportunities for pupils to undertake experiments, to make their own generalizations and to negotiate appropriate interpretations. They may reflect, therefore, a discovery or social constructivist perspective depending on the way that they are implemented.

Overall, the dominant model appears to be a transmission model with emphasis being given to teacher exposition, focused question and answer interactions, and closed practical work. Whilst such procedures might superficially offer the appearance of whole class discussion, research has shown that teachers' questions are overwhelmingly closed (Edwards and Mercer 1987) and whose primary function is evaluative and a mechanism for controlling classroom talk (Lemke 1990). Rather than assisting the development of understanding and co-construction of knowledge as learners contribute their half-formed understandings, such procedures invariably lead to 'guessing what is in teacher's mind'. Thus, one of us was perhaps somewhat premature in cautioning about social constructivist approaches that placed an over-reliance on discussion and co-construction whilst ignoring the importance of 'telling' (Osborne 1996). For as Hacker and Rowe's (1997) recent study suggests, within English and Welsh classrooms, it is the teacher as informer and not teacher as facilitator which is the predominant role model.

Exploring reasons for the persistence of traditional pedagogical practices

Social constructivist perspectives on learning science (e.g. Johnson 1990) have been current in England since the mid 1980s when they were the focus of the Secondary Science Curriculum Review (SSCR 1987). Since then, they have featured in many initial teacher training courses and in-service programmes. Yet, although social constructivist perspectives may predominate in the thinking of science educators, they are not reflected in classroom practice. Why do we still find the transmission model dominating science classroom teaching?

We suggest that there are two key explanations. The first, which is internal to schools and classrooms, relates to the fact that pedagogy is essentially a conservative activity; the skills and practices that make up the craft of teaching are learned through experience and changes in such practices are difficult to bring about. The second explanation is external to schools and classrooms; it relates to the pressures which teachers and schools are increasingly being subjected to as a consequence of accountability and the marketization of education (e.g. Ball 1990, Apple 1992).

Training old dogs to do new tricks?

The patterns of pupil and teacher interaction observed in our study (e.g. the predominance of teacher exposition and question–answer sequences) are not novel; they have been documented across countries and across decades in time. For example, our observation that deliberative interactions occupied less than 2% of total class time on average was mirrored in an observation study of 1000 elementary and secondary classrooms, undertaken in the USA by Goodlad (1984), where open discussion occupied an average of 4–7% of total class time.

Our conclusions also mirror those from research conducted in England nearly two decades ago. In a study of group work in science lessons undertaken by Sands (1981), the activities of pupils in 18 mixed ability classes, from the first 3 years of secondary schooling, were observed. Her findings resonate with our own to a remarkable degree. In particular she noted the following.

(i) All the observed groups were undertaking practical work. In no lessons were groups used for other activities.
(ii) No opportunities were given for groups to design experiments or interpret results.
(iii) Any imaginative, analytical or enquiry-based thinking was done by the teacher with the whole class.
(iv) Rarely were there follow-ups to the practical group work which involved the sharing of experiences.
(v) Pupil talk during group practical work involved no reasoning activity (e.g. the evaluation of an experiment, interpretation of an observation, or relating of an investigation to a theory).

In her summary, Sands (1981: 768) commented:

> What happened to the idea of groups in which children exchanged views and ideas, where teachers initiated and encouraged discussion, or where the teacher's questions were designed to stimulate and not only to elicit facts? . . . And what about the idea of groups existing which, even in the context of a traditional practical lesson, are allowed to grow so that . . . one sees the development of initiative and leadership, cooperation, decision-making and responsibility?

The pressure of the National Curriculum

The second key explanation relates to the socio-political climate in which schools are currently operating. Apple (1992: 782) offers an analysis of the economic and ideological influences on schools in terms of a conflict between a previous liberal consensus and an emergent zeitgeist centred on education for economic utility. He comments:

> No longer is education seen as part of a social alliance . . . A new alliance has been formed, one that has increasing power in educational and social policy. This power bloc . . . aims at providing the educational conditions believed necessary both for increasing profit and capital accumulation.

This new alliance, which can be described as reflecting a *technocratic orientation,* views education as a commodity to be bought and sold in the market place. The technocratic orientation to education sees learning not as the development of critical faculties of individuals, but as the mastery of given bodies of knowledge and skills selected to serve the interests of the political/industrial world. Evaluation and assessment is an essential part of this orientation to education: it is necessary to find out the extent to which learners have achieved specified learning goals in order to determine the efficiency of aspects of the system.

Such a system of accountability is having a major impact on education in England and Wales: pupils are now faced with far more formal assessment than ever before and the results of these assessments are used, not only for ranking individual pupils, but for ranking local authorities, schools, departments and individual teachers. The institutional importance of the results of assessment tests means that schools and teachers place great emphasis on learning activities that enhance test scores. The consequences of this technocratic orientation for science education can be seen in the results of our observation study as elaborated through the teachers' comments. Science teachers are under pressure to emphasize the recall of unrelated ideas and concepts of science, and to give priority to 'covering the syllabus'. They feel that the time pressures they are working under mean that they are unable to pay attention to broader issues, e.g. how scientific and technological knowledge is created, or to discuss the social and ethical implications of scientific developments (Cross and Price 1992).

In short, we argue that the technocratic orientation to education is leading to a regressive pedagogy that emphasizes rote learning at the expense of deeper understanding. This is the antithesis of our vision for a science education with argumentation at its heart. Bearing in mind that few science teachers have so far developed the skills necessary to include argumentation in their pedagogical repertoire (Boulter and Gilbert 1995), the conservatism of pedagogy combined with a technocratic orientation to education does not augur well for the hopes of social constructivist educators. To realize such hopes will require a highly concerted effort.

The genesis of change?

There has always been opposition to change as far as pedagogy is concerned. Now, in the UK, where more responsibility for initial teacher education rests with teachers in schools, the inertial effect of 'current practice' is likely to be even more restrictive. To provide more opportunities for discussion and activities in which pupils themselves took responsibility for their own learning would, indeed, constitute a major change in pedagogy. Some indication of the foundations on which relevant practices could be developed is offered by the comments of the teachers recorded earlier. More fundamentally, change is impossible without a widespread recognition that current practices offer little or no opportunity for the discussion of socio-scientific issues. In reiterating the findings of Sands (1981), and Lunzer and Gardner (1979), therefore, the findings of this research support the argument that the impact of the national curriculum in the UK has been conservative and regressive.

Yet, modern societies require future citizens with a different set of competencies. The European Commission's White Paper on Education (1995) and training argues that sustaining a healthy and participatory democracy requires citizens 'who are capable of making considered decisions' by 'enabling them to fulfil an enlightened role in making choices which affect the environment'. Similarly, the UK government's Advisory Group for Education for Citizenship (1998) argues that schools should provide young people with 'an armoury of essential skills: listening, arguing, making a case; and accepting the greater wisdom or force of an alternative view'. Yet, how can young people learn how to make considered decisions and discuss issues of a socio-scientific nature if their education in science fails to provide them with the opportunity to practise the skills associated with argument by considering issues of a controversial nature? Moreover, if the recurrent stress by employers for schools to produce individuals who are 'flexible', 'adaptable' and 'good communicators', rather than individuals with a detailed knowledge of science curriculum *per se*, is a true reflection of the current needs of society, then are existing curricula in danger of becoming an anachronism, irrelevant both to society and to our children? In short, science education persists with the fallacy of miscellaneous information – the belief in the usefulness of disparate, but unrelated facts – the force that holds us to the Earth, the order of the planets, the nature of chemical bonds (Cohen 1952). The need for such specific information becomes increasingly questionable in a society which offers information on tap when, in contrast, the ability to sift, sort and interrogate information, and the ability to assess its import and significance becomes an evermore important skill.

Changing the current orientation of the ship of science education will never be easy. However, the first task of those working within the vessel is to continue to warn, and stridently at that, not only of the irrelevance of the current direction but that the ship is in danger of foundering on the rocks. Such initiatives and arguments can be found within recent reports published in both the UK and America (American Association for the Advancement of Science 1998, King's College London 1998). Sowing the seeds of dissatisfaction both within the body politic of science education and with the wider public is, therefore, an *a priori* necessity for any reform initiative. Similarly, overcoming the strong conservative influence of pedagogical culture will require convincing teachers of the necessity for change. Importantly, this will also require equipping new science teachers with the skills necessary for applying social constructivist principles. Teachers require enculturation into the practice of science teaching just as their students need enculturation into the practice of science. In particular, we must ensure that appropriate resource materials are available for scaffolding teachers' initial attempts at adopting new techniques, e.g. those that involve argument.

To borrow an evolutionary metaphor, without a mechanism for systematically encouraging innovation and curriculum development, existing curriculum frameworks do not encourage adaptation and the growth of diversity. Consequently, new forms cannot evolve and be tested to see if they offer improvement. As a result, the system cannot easily accommodate any changes in the social context which may require a different set of competencies and skills compared to those fostered by existing curricula. The strong message of evolution is that lifeforms that fail to adapt merely become extinct. Hence, the consistent failure of science education to transform and adapt from its extant 19th century origins now places it under threat. It is our view, then, that the changes in the pedagogy argued for in this paper are of great educational importance for the health, vitality and relevance of science education, and the struggle to promote change is therefore a mantle of responsibility that falls on us all.

References

Advisory Group for Education for Citizenship (1998) Education, Citizenship & Teaching Democracy. Report No 98/155, Qualifications and Curriculum Authority, London.

Alexopoulou, E. and Driver, R. (1997) Small group discussions in physics: peer interaction modes in pairs and fours. *Journal of Research in Science Teaching,* 33, 1099–1114.

American Association for the Advancement of Science (1998) *Blueprints for Reform: Science, Mathematics and Technology Education* (New York: Oxford University Press).

Apple, M. (1992) Educational reform and educational crisis. *Journal of Research in Science Teaching,* 29, 779–789.

Association for Science Education (1986) *Science and Technology in Society: General Guide for Teachers* (Hatfield: Association for Science Education).

Ball, S. (1990) *Politics and Policy Making in Education: Explorations in Policy Sociology* (London: Routledge).

Barnes, D. (1977) Talking and writing in science lessons. *Cambridge Journal of Education,* **7**, 138–147.

Barnes, D. and Todd, F. (1977) *Communication and Learning in Small Groups* (London: Routledge & Kegan Paul).

Boulter, C. J. and Gilbert J. K. (1995) Argument and science education. In P. S. M. Costello and S. Mitchell (eds) *Competing and Consensual Voices: The Theory and Practice of Argumentation* (Clevedon: Multilingual Matters).

Bulman, L. (1985) *Teaching Language and Study Skills in Science* (London: Heinemann Educational Books).

CLIS (1987) *CLIS in the Classroom* (Leeds: Centre for Studies in Science and Mathematics Education, University of Leeds).

Cohen, I. B. (1952) The education of the public in science. *Impact of Science on Society,* **3**, 78–81.

Cross, R. T. and Rice, R. F. (1992) *Teaching Science for Social Responsibility* (Sydney: St. Louis Press).

Dillon, J. T. (1994) *Using Discussion in Classrooms* (Buckingham: Open University Press).

Driver, R. (1987) Theory into practice: a constructivist approach to curriculum development. In P. Fensham (ed.) *Development and Dilemmas in Science Education*, London: Falmer Press, pp. 133–149.

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

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

Druker, S. L., Chen, C. and Kelly, G. J. (1996) Introducing content to the Toulmin model of argumentation via error analysis. Paper presented at NARST meeting, Chicago, USA.

Duit, R., Goldberg, F. and Niedderer, H. (1991) Research in physics learning: theoretical issues and empirical studies. *Proceedings of an International Workshop*, Kiel, IPN.

Edwards, D. and Mercer, N. (1987) *Common Knowledge: The Development of Understanding in the Classroom* (London: Methuen).

European Commission (1995) White paper on education and training: Teaching and learning—Towards the learning society (White paper). Office for Official Publications in European Countries, Luxembourg.

Geddis, A. (1991) Improving the quality of classroom discourse on controversial issues. *Science Education*, 75, 169–183.

Goodlad, J. (1984) *A Place Called School* (New York: McGraw-Hill).

Hacker, R. J. and Rowe, M. J. (1997) The impact of National Curriculum development on teaching and learning behaviours. *International Journal of Science Education,* 19, 997–1004.

Hanson, N. R. (1958) *Patterns of Discovery* (Cambridge: Cambridge University Press).

Jiménez-Aleixandre, M. P., Gugallo-Rodríguez, A. and Duschl, R. (1997) Argument in High School genetics. Paper presented at the NARST Conference. March.

Johnson, K. (ed.) (1990) *Interactive Teaching in Science: Workshops for Training Courses* (Hatfield: Association for Science Education).

King's College London (1998) *Beyond 2000: Science Education for the Future* (London: King's College London).

Krummheuer, G. (1995) The ethnography of argumentation. In P. Cobb and H. Bauersfeld (eds) *Emergence of Mathematical Meaning* (Hillsdale, NJ: Lawrence Erlbaum).

Kuhn, T. S. (1962) *The Structure of Scientific Revolutions* (Chicago, Il: University of Chicago Press).

Lave, J. (1988) *Cognition in Practice: Mind, Mathematics and Culture in Everyday Life* (Cambridge: Cambridge University Press).

Lemke, J. L. (1988) Games, semantics and classroom education. *Linguistics and Education,* 1, 81–99.

LEMKE, J. L. (1990) *Talking Science: Language, Learning, and Values* (Norwood, NJ: Ablex).
LUNZER, E. and GARDNER, K. (1979) *The Effective Use of Reading* (London: Heinemann Educational).
NORRIS, S. P. and PHILLIPS, L. M. (1994) Interpreting pragmatic meaning when reading popular reports of science. *Journal of Research in Science Teaching,* 31, 947–967.
OSBORNE, J. F. (1996) Beyond constructivism. *Science Education,* 80, 53–82.
RICHMOND, G. and SHRILEY, J. (1996) Making meaning in classrooms: social processes in small group discourse and scientific knowledge building. *Journal of Research in Science Teaching,* 33, 839–858.
SANDS, M. (1981) Group work in science: myth and reality. *School Science Review,* 62, 765–769.
SECONDARY SCIENCE CURRICULUM REVIEW (1989) *Better Science: Making it Happen* (London: ASE/Heinemann).
SOLOMON, J. (1991) Group discussions in the classroom. *School Science Review,* 72, 29–34.
TOULMIN, S. (1958) *The Uses of Argument* (Cambridge: Cambridge University Press).
VYGOTSKY, L. (1978) *Thought and Language* (Cambridge, MA: MIT Press).
WERTSCH, J. (1991) *Voices on the Mind: A Socio-Cultural Approach to Mediated Action* (Cambridge: Cambridge University Press).

Appendix A. Types of activity, pupil grouping and teacher–pupil interactions coded in the observation schedule

Pupil Activity (PA)

The main types of activity in which pupils are engaged during science lessons.

Listening. When teacher and pupils are engaged in some form of discourse-based interaction. For instance, this might include: reviewing what has been covered in a previous lesson; teacher explaining a scientific idea; teacher telling the pupils what to do for homework, etc. Notice that it is not exclusively attending to teacher talk (although the teacher will be involved in the activity) as the class may be listening to an idea being explained by a pupil, or may even be watching a video recording.

Reading. When the pupils are either reading from a text silently or taking turns to read out loud. This would not include reading questions from a worksheet, although it would include reading text upon which a question was based if the reading involved was substantial.

Set exercises. When pupils have been set problems, which may involve numerical or written responses, but which generally tend to be structured and require a concise response.

Copying. When pupils are passively recording information that has been presented directly to them from a textbook, board, teacher talk, etc. In the case of copying down what a teacher is saying, the description 'copying' is taken to override the description 'listening'.

Open paper and pencil task. When pupils are involved in creative or reflective work which requires more of an intellectual input than copying would. This is distinct from 'set exercises' and is intended to cover tasks that do not require simple, concise, structured responses. It might involve drawing apparatus used in practical work, tabulating resulting, literature searches, writing up and interpreting results.

Observing demonstration. When pupils are observing their teacher demonstrate a practical investigation. When 'listening' also occurs, the description 'observing demonstration' should override it.

Closed practical task. When pupils are engaged in a practical investigation with a methodology predetermined by their teacher or text book.

Open practical task. When pupils are engaged in a practical investigation without a predetermined methodology.

Preparing or clearing away. When pupils are readying themselves for conducting an activity or are clearing away after an activity. This may involve handing books out, assembling apparatus, moving seats, washing up or putting apparatus away.

Group discussion. When pupils have been arranged into one or more groups in order to discuss a specific question related to science. This might involve the discussion of how to explain a scientific phenomenon, the moral issues surrounding a scientific invention, etc.

Pupil Working Group (PWG)

The social setting for the main activity in which pupils are engaged.

Whole class activity. When the teacher engages the whole class in one activity. This may, e.g. involve 'listening' or 'observing demonstration'.

Small group activity. When groups of students work together to develop a group product. This may, e.g. involve 'open paper and pencil task', 'group discussion' or 'closed practical task'.

Individual activity. When pupils work by themselves to develop their own product. There may or may not, be an element of collaboration here. This may, e.g. involve 'copying', 'reading' or 'closed practical task'.

Pupil and Teacher Interactions (P&TI)

Discursive interactions that occur between pupils and teachers whilst engaged in the main activity.

Teacher giving instructions. When pupils are being instructed what they ought to be doing next, how to do something, etc. This extends to include disciplining and classroom management.

Teacher explaining science. When a teacher is explaining an idea, describing a phenomenon, summarizing a previous lesson, etc.

Question–answer interactions. There are sections of discourse of a genre typical of lessons. They are controlled by the teacher and involve a question, answer and evaluation sequence. Teachers use them to review previous work, homework assignments, etc.

Deliberative interactions. These are sections of discourse in which teacher and pupils are engaged in a more extended or deeper discussion of a question or issue. They differ from question–answer interactions' in that the teacher is interested in the thinking behind the responses that pupils give and is likely to demonstrate this by encouraging pupils to develop their answers or be explicit about their reasoning.

Appendix B. A reliability study

A reliability study was undertaken to assess the extent to which two trained observers would agree on their coding for the same lesson. This study was conducted by PN and a research assistant (RA). The RA was trained to use the schedule during 1 day of observation: two lessons were jointly observed in the morning and two in the afternoon, each followed by a debriefing. A week later, PN and RA jointly observed and scored three lessons; the data were subsequently analysed for agreement.

The scoring of activities within both the *PWG* and *PA* sections is mutually exclusive; i.e. there should only be one box marked, for each section, for each 30s interval. This means that, for each 30s interval, there are 44 (4×11) possible permutations for the characterization of an activity. The total number of occasions that each of these 44 permutations was recorded, over the course of each lesson, was summed for each observer separately. The 44 repeated measures for the two observers were subtracted from each other and the reliability coefficient was simply a proportional representation of the overall degree of agreement.

The method can be illustrated with the following simplified example. Imagine that Observer 1 recorded the first 60 columns of a 1h long lesson as ('whole class activity', 'listening') and the second 60 columns as ('whole class activity', 'observing demonstration'). Imagine also that Observer 2 recorded a total of 60 columns as ('whole class activity'; 'listening'), 30 columns as ('whole class activity', 'observing demonstration') and 30 columns as ('whole class activity', 'closed practical task'). A reliability coefficient would be assigned on the basis that both observers scored 60 columns as ('whole class activity', 'listening') and 30 columns as ('whole class activity', 'observing demonstration'). This represents an agreement at the aggregate level for 90 out of 120 columns which translates into a coefficient of 75%. This formula is crude, of course, because agreement at the aggregate level may not reflect precise agreement at the individual column level. However, as the results from the observation schedule were presented at an aggregate level, this approach seemed valid.

Reliability coefficients were calculated for *P&TI* in a similar fashion. The results for the three jointly observed lessons are presented in table B1 below. Note that, in Lesson 3, one observer systematically recorded a practical as 'open', whereas the other recorded it as 'closed'. The fourth column of table B1 presents the coefficient that would have resulted had they agreed on this characterization of the investigation.

The high reliability coefficients indicate that, even after 1 day training, the observation schedule was fairly easy to apply consistently. In fact, because of the nature of the recording process, it would be easy for the reliability figures to have been low despite only minor differences in recording. This illustrated through the contrast between the original and adjusted results for Lesson 3.

Table B1. Reliability coefficients indicating the level of agreement between two observers for three lessons.

	Lesson 1	*Lesson 2*	*Lesson 3 (original)*	*Lesson 3 (adjusted)*
Duration of lesson (min)	51.5	52.0	60.0	60.0
PA × *PWG* reliability (% agreement)	81.7	75.0	72.5	90.8
P&TI reliability (% agreement)	84.7	89.7	79.2	79.2