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Learning to Teach Argumentation: Research and development in the science classroom

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The research reported in this study focuses on an investigation into the teaching of argumentation in secondary science classrooms. Over a 1-year period, a group of 12 teachers from schools in the greater London area attended a series of workshops to develop materials and strategies to support the teaching of argumentation in scientific contexts. Data were collected at the beginning and end of the year by audio-recording and video-recording lessons where the teachers attempted to implement argumentation. To assess the quality of argumentation, analytical tools derived from Toulmin's argument pattern were developed and applied to classroom transcripts. Teachers' use of argumentation developed across the year, the pattern of use was teacher-specific, as was the nature of change. To inform future professional development programmes, transcripts of five teachers, three showing a significant change and two showing no change, were analysed in more detail to identify features of teachers' oral contributions that facilitated and supported argumentation. All teachers attempted to encourage a variety of processes involved in argumentation; teachers whose lessons included the highest quality of argumentation (Toulmin's argument pattern analysis) also encouraged higher-order processes in their teaching. The analysis of teachers' facilitation of argumentation has helped to guide the development of in-service materials and to identify the barriers to learning in the professional development of less experienced teachers.

Introduction

The importance of developing scientific literacy has been highlighted in recent documents and debates within science education (Millar & Osborne, 1998; Norris & Phillips, 2003). The publication of the American Association for the Advancement of Science edited volume on enquiry (Minstrell & Van Zee, 2000), the release of the *Inquiry and the National Science Education Standards* (National Research Council,

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2000), and the inclusion of scientific enquiry as a separate strand in the English science national curriculum all point to a commitment that science education should be concerned with more than knowledge of scientific facts; it should place value and emphasis on the processes of critical reasoning and argument that enable students to understand science as a way of knowing (Driver, Leach, Millar, & Scott, 1996; Driver, Newton, & Osborne, 2000; Millar & Osborne, 1998). Science education requires a focus on how evidence is used to construct explanations; that is, on examining the data and warrants that form the substantive basis of belief in scientific ideas and theories, and on understanding the criteria used in science to evaluate evidence (Osborne, Erduran, & Simon, 2004a). The competence to comprehend and follow arguments of a scientific nature is, we would contend, a crucial aspect of scientific literacy in its fundamental sense. Inferring meaning from science texts requires the ability to recognize the standard genres of science, their appropriate use, and, in the case of argument, to evaluate the claims and evidence advanced. Thus, only if argumentation is specifically and explicitly addressed will students have any opportunity to explore its use in science. If, as Norris and Phillips (2003) would argue, literacy in its fundamental sense means comprehending, interpreting, analysing and critiquing texts, the study of argument and its construction, then the evaluation of the data and warrants and the consideration of opposing hypotheses must become a core pedagogic practice within science.

In a context where conceptual goals predominate, emphasizing alternative goals for classroom pedagogy is notoriously difficult. The limited time spent on scientific enquiry in order to satisfy the English national curriculum requirements highlights the difficulty (Donnelly, Buchan, Jenkins, Laws, & Welford, 1996). Yet there are convincing arguments that addressing epistemological issues may help to advance conceptual understanding; for example, through the use of texts that include arguments refuting common misconceptions (Alvermann & Hynd, 1986; Hynd & Alvermann, 1986; Hynd, Alvermann, & Qian, 1997). The teaching of argumentation through the use of appropriate activities and pedagogical strategies is, we would argue, a means of promoting epistemic, cognitive and social goals as well as enhancing students' conceptual understanding of science (Osborne, Erduran, & Simon, 2004b).

The adoption of any new approach that promotes the use of argument would require a shift in the nature of the discourse in science lessons. The focus on the language of the science classroom in recent years (Lemke, 1990; Mortimer & Scott, 2003; Sutton, 1992) has increased our awareness of how teachers' use of language influences the pedagogy of science. The analyses offered by Lemke and others show how the use of language reflects teachers' implicit beliefs about science teaching and learning. These beliefs, articulated through most discourse of the classroom, present a particular view of science—essentially as a body of unequivocal and uncontested knowledge. To transform that model from one that suggests science is all about certain and absolute knowledge, our view in common with others is that the discourse of the science classroom needs to be more deliberative or dialogic (Mortimer & Scott, 2003; Scott, 1998). To shape a new world, teachers need to adopt a new discourse. This is not simply a case of changing their vocabulary, but,

more fundamentally, assimilating new goals that will foreground and support the discourse of argumentation in their teaching.

Previous research on argument includes a range of different perspectives on the role of argumentative discourse in science education (Osborne et al., 2004a; Erduran, Simon, & Osborne, 2004). One significant contribution to the original thinking behind the research reported here was the work of Kuhn (1991). Her research highlights the fact that, for the overwhelming majority, the use of valid argument does not come naturally and is acquired only through practice. The implication for education is that argument is a form of discourse that needs to be explicitly taught, through the provision of suitable activity, support, and modelling. More recently, other researchers have reached similar conclusions (Hogan & Maglienti, 2001; Zohar & Nemet, 2002).

The research presented in this paper has therefore sought to examine ways in which teachers can appropriate the discourse of argumentation and whether changes occur in the nature of teachers' classroom interactions as they engage in a professional development programme. In undertaking this work, we have found it useful to make a distinction between *argument* and *argumentation*. Argument refers to the substance of claims, data, warrants, and backings that contribute to the content of an argument; whereas argumentation refers to the process of assembling these components (in other words, of arguing). Through providing students with tasks that require discussion and debate, it was envisaged that teachers could engage students in the construction of arguments through the process of argumentation. Oral work was therefore an important aspect of argumentation tasks, but could be supported by the use of writing both during debate and as follow-up work in order to enhance students' argumentation (Rivard & Straw, 2000). The focus of the professional development of teachers was primarily on the development of oral discussion, as this aspect of pedagogy had been shown to be minimal in typical science lessons (Newton, Driver, & Osborne, 1999). The professional support for teachers' practice in argumentation was part of a wider research agenda that sought to find ways of enhancing young people's skills by:

1. identifying some of the pedagogical strategies necessary to promote argumentation skills in science lessons;
2. trialling the pedagogical strategies and determining the extent to which their implementation enhances teachers' pedagogic practice with argumentation; and
3. determining the extent to which lessons that follow these pedagogical strategies lead to enhanced quality in students' arguments.

This paper is concerned with the second of these objectives. The analysis of teachers' classroom practices and interactions is informing further professional development of teachers in this aspect of science education.

Professional Development of Teachers and Analyses of Argumentation

The work with teachers built on the knowledge of innovation and change established through a series of theory-driven initiatives involving teacher professional

development undertaken at King's College London (e.g., Adey, Shayer, & Yates, 2001; Black, Harrison, Lee, Marshall, & Wiliam, 2002, 2003; Jones, Simon, Black, Fairbrother, & Watson, 1992; Shayer & Adey, 2002). These initiatives were informed by the wider literature on teacher change (e.g., Fullan, 1991) and owe much of their success to the way in which teachers worked in partnership with researchers to provide a sense of ownership and value through participation in the development process (Ogborn, 2002).

The research on the development of argumentation in school science involved a partnership between researchers and teachers. We, the researchers, provided both theoretical ideas and practical resources to stimulate change in teachers' practice (Loucks-Horsley, Hewson, Love, & Stiles, 1998), while teachers made important contributions to our thinking. Through working collaboratively with teachers to develop argumentation activities and teaching strategies and through analysing teachers' practice as these were implemented in classrooms, we hoped to gain insights that would inform subsequent curriculum initiatives aimed at a wider audience of practitioners.

Achieving this successful partnership with teachers involved working within a number of constraints. First, the curriculum followed by teachers was often rigid; and teachers had to plan carefully how to include alternative activities that allowed argumentation to take place. Second, although we provided funding to release teachers to attend meetings, there was a limit to the frequency with which they could be absent from school to share ideas and collaborate in the development. Finally, there were limitations to the on-site support or coaching (Joyce & Showers, 1988) that the research team could provide. In spite of these constraints, we hoped that our model of professional development would be successful in stimulating changes in practice. Early approaches to teacher learning that had little sustained impact were underpinned by beliefs that teacher learning is a linear process and that educational change is a "natural consequence of receiving well-written and comprehensive instructional materials" (Hoban, 2002, p. 3). A more complex view of professional development is required, incorporating professional learning systems that only bring about sustained change over a long period of time. From the outset we were aware that educational change is complex and takes time (Fullan, 2001), and it was never anticipated that fundamental and substantial changes could be achieved within the time scale of 1 year. However, within the UK context of accountability and high stakes assessment, our aim was to initiate change that, with detailed analysis, could inform professional development programmes that could be implemented within systems experiencing curricular constraints.

To achieve our research objective, we incorporated many of the elements that Supovitz and Turner (2000, p. 964) identified as critical to high-quality professional development. Such development must:

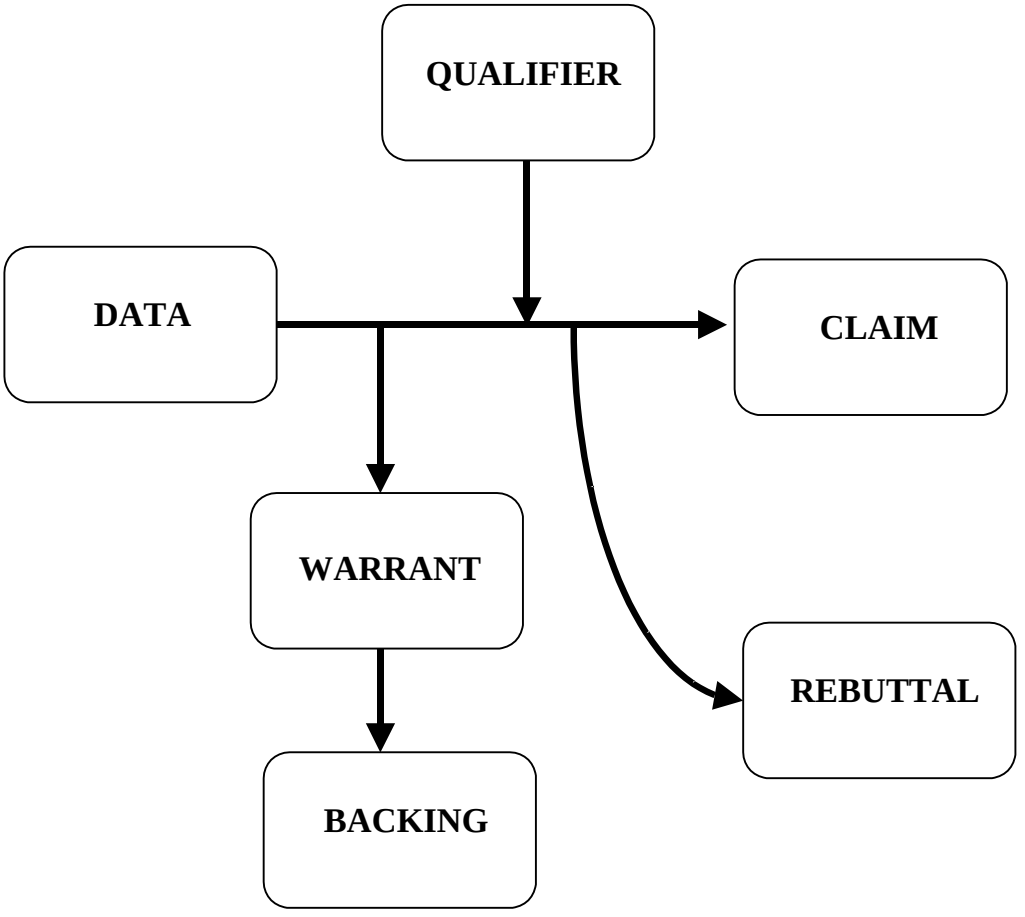
- immerse participants in inquiry, questioning, and experimentation;
- be intensive and sustained;
- engage teachers in concrete teaching tasks and be based on teachers' experiences with students;

- focus on subject-matter knowledge and deepen teachers' content skills;
- be grounded in a common set of professional development standards and show teachers how to connect their work to specific standards; and
- be connected to other aspects of school change.

Within the timescale of 1 year, as well as attempting to initiate change, we were also developing our knowledge of pedagogical strategies for argumentation; therefore, it was not feasible to address the elements of sustainability or connectedness to other aspects of school change. Rather, our research was intended to identify such strategies and examine changes in classroom practice of individual teachers who were willing to initiate change. We therefore focused on ways in which teachers supported processes described as classroom culture, including the facilitation of student discussion and encouragement of students to supply evidence to support their claims. Supovitz and Turner (2000) established a statistical relationship between professional development and teacher-reported classroom culture; however, their research leaves unanswered the question of *how* professional development is linked to changes in practice.

To help individual teachers initiate change, we were conscious of the need to produce readily available ideas that were simple to implement and to help teachers construct the knowledge they needed for understanding the purpose of teaching argumentation (Pogrow, 1996). Moreover, we knew that the role of the teacher in an argumentation activity would be likely to change, as encouraging students to provide evidence for justification of arguments would mean a shift away from the role of an authority figure providing right answers (Bay, Reys, & Reys, 1999). We were already aware of the advantages, identified by Bay et al., of providing the opportunity to enable teachers to meet and work collaboratively during the school day and to try out student activities. In doing so, we were providing teachers with a forum for deliberation about practice away from the norm of privacy that dominates most schools (Spillane, 1999). Although this forum facilitated the important process of reflection on previous experience (reflection-on-action), it was difficult to anticipate the extent to which the professional development would initiate the process of reflection-in-action, or reframing (Munby, Cunningham, & Lock, 2000; Munby & Russel1, 1992; Schon, 1987), that would result in constructing new pedagogical understanding of argumentation in science.

The analysis of argumentation discourse in science lessons was approached from two different perspectives. First, the analysis focused on ways in which the quality of argument could be determined. We needed to find an analytical framework to identify and evaluate argumentation, in order to see whether improvements in pedagogy occurred over time. It was also important to develop a means of evaluating argumentation with teachers, so that they could respond to students' discussions formatively. A suitable analytic framework is Toulmin's (1958) model (Figure 1), referred to here as Toulmin's argument pattern (TAP). His model has been used as a basis for characterizing argumentation in science lessons (Russell, 1983) and used in other coding schemes (e.g., Jiménex-Aleixandre, Rodríguez, &



Claims:	Assertions about what exists or values that people hold.
Data:	Statements that are used as evidence to support the claim.
Warrants:	Statements that explain the relationship of the data to the claim.
Qualifiers:	Special conditions under which the claim holds true.
Backings:	Underlying assumptions that are often not made explicit.
Rebuttals:	Statements that contradict either the data, warrant, backing or qualifier of an argument.

Figure 1. Toulmin's argument pattern

Duschl, 2000). A fuller rationale for the use of Toulmin's model in this research is reported elsewhere (Erduran et al., 2004). The analysis also focused on the epistemic and argumentative operations (Pontecorvo, 1987) adopted by students; that is, their reasoning functions and strategies for constructing valid arguments. Therefore, the analysis of argumentation concentrated on specific features: the extent to which students and teachers have made use of data, claims, warrants, backings, qualifiers, and rebuttals; and the extent to which they have engaged in

claiming, justifying, and opposing the arguments of each other. The use of TAP enabled us to provide a quantitative analysis of the extent and quality of argumentation facilitated by the teachers.

Second, to supplement this quantitative analysis, a more detailed analysis of how argumentation was facilitated by teachers was undertaken to inform future professional development. In developing their practice, teachers need to foreground the processes that enhance argumentation and be aware of the epistemic nature of the task when teaching. The research therefore examined how teachers' goals were reflected in practice through their classroom talk. From a socio-cultural perspective, investigating the ways in which people think begins by investigating the ways in which they talk (Mortimer & Scott, 2003). The analysis of teachers' oral contributions demonstrated how epistemic goals were apparent in their interactions, both in whole class and small group settings. For example, the act of asking students to provide reasons for their claims reflected a teaching goal that students should show the process of justification. An analytical framework that focused on teachers' oral contributions was developed qualitatively through the detailed examination of a small number of cases. The initial development of this framework while analysing the cases of two teachers was reported in Simon, Osborne, and Erduran (2003). The analysis showed that, although both teachers aimed to encourage and facilitate positioning and justification, only one teacher focused on the importance of counter-argument (rebuttal of claim and provision of a counter-claim). This analysis was refined and extended through the use of more contrasting cases, to present a possible hierarchy of teaching goals.

Research and Development Approach

In addressing our research objectives, we supported teachers in the development of argumentation activities in two contexts—a socio-scientific context and a scientific context. The former was included as many debates in the public domain are of this kind. Also, such issues provide a context in which students do have prior knowledge and experience on which they can draw in their discussions. Scientific contexts are important, however, as these provide a context for exploring the justification for belief in the scientific world view, for refuting erroneous ideas, and for examining the fundamental rationality of science.

A group of interested teachers was established for preliminary work to develop activities and strategies to support argumentation. From this group, 12 teachers were selected who were willing to participate for the duration of the project and who were prepared to take the risk of adopting unfamiliar teaching approaches. These teachers had a range of experience and came from inner-city and suburban schools located in the Greater London area. Their students were from mixed ethnic groups representative of a range of academic ability. The students who took part in this research were all drawn from Year 8 (aged 12–13 years), a year in which they and their teachers would be free from the constraints of public examinations.

Professional Development

Over the course of the first year of our project, the focus was on the developing skills of the teachers and the second objective of the research—to see how the teachers enhanced their practice with argumentation. Research into practice was therefore combined with a professional development programme. During the year, six half-day workshop meetings were held at King's College London. Data were collected on teachers' practice with argumentation both after the initial meeting and again 1 year later. The meetings were developed on the basis of our theoretical perspective on argumentation and according to the needs of the teachers as the year progressed. The contents of the workshops were not predetermined at the outset, as an objective of the research was to explore ways in which guidance could be developed. Although we provided ideas, the aim was to facilitate teacher development through encouraging teachers to take ownership by designing their own activities (Ogborn, 2002). Also, as previous studies have shown the importance of underlying theory to practice (Joyce & Showers, 1988), a means for communicating this was developed.

The workshops served to introduce the teachers to a possible format for a lesson about funding a zoo, the socio-scientific situation that was to provide a data source for the research. All the teachers were provided with a detailed plan of how they might carry out this lesson, so that there would be an opportunity at the outset to observe and record argumentation in the lesson. The lesson format included advice about how teachers might engage students' interest—with a letter inviting students to decide whether a new zoo should be funded (see Appendix 1). Teachers could brainstorm ideas for and against the zoo, drawing on students' prior knowledge and information collected from different sources. The emphasis would then be on small group discussions of three to four students to produce justified arguments for and/or against the zoo. Students could then share these arguments with the whole class in some form; for example, as presentations or as a class debate. Inevitably, each teacher adapted this lesson format in their own way, although all used the same basic idea.

The teachers were also introduced to a range of different kinds of argumentation activities and pedagogical strategies. To develop their pedagogic practice with argument, they were asked to incorporate nine argument-based lessons across the course of the year. Hence it was important to provide some ideas as starting points from which they could design their own activities. The English national curriculum's requirement to teach scientific enquiry focusing on ideas and evidence in science served as the justification. This aspect was new to many teachers and was not fully implemented in their classrooms. Teachers were unsure how to approach the teaching of scientific uncertainty, and the use of activities involving small group discussion was not established practice (Newton et al., 1999). The gulf between recommendation and pedagogic practice suggested a need for teachers to gradually incorporate argumentation into their teaching. In order that teachers were confident of fulfilling existing curricular commitments while taking on something that was new for them, it was envisaged that they would only be able to implement activities with uncertain outcomes about once every month.

Through the workshops we also provided advice about how to structure classroom activities to emphasize scientific argumentation through encouraging the use of evidence to justify a position and how to enhance scientific argumentation by posing open questions. A set of arguing prompts were devised, designed to elicit justification. Questions included "Why do you think that?", "Can you think of another argument for your view?", "Can you think of an argument against your view?", and "How do you know?"

To help teachers understand our analytical perspective, TAP was introduced to the teachers to help them clarify what was involved in the process of constructing arguments. Drawing on the literature on teaching students to write (Bereiter & Scardamalia, 1987), teachers were also presented with writing frames to support the process of writing through providing stems such as "My argument is …", "My reasons are that …", or "I would convince someone who does not believe me by …". These stems provide prompts necessary to construct a written argument and help record notes of discussions. Thus, the workshops were devoted to very tangible strategies for supporting the process of argumentation and the construction of arguments through both oral and written work (Rivard & Straw, 2000).

The workshop meetings also provided opportunities for teachers to discuss activities and share their experiences. It was clear from such discussions that teachers differed greatly in their perspective on argument. The discussion between the teachers was important because, through listening to others' perspectives, teachers had an opportunity to reshape their own views and the researchers to plan future meetings. A member of the research team visited each teacher three times during the year to observe and support the implementation of the activities. These classroom observations and interactions also served to provide us with data to inform the workshop meetings.

Data Sources, Collection, Analyses, and Results

To assess the teachers' progress, each teacher was videotaped and audio-recorded while they taught the zoo lesson, at the beginning of the professional development programme and again 1 year later. The audio-recordings were fully transcribed to capture all the teachers' oral contributions and interactions with students. The analysis of the lesson transcripts was undertaken in two stages.

The first aim was to compare the nature and quality of the argumentation generated in the classroom to determine what progress and development all 12 teachers had made over the course of the year. Toulmin's (1958) model of argument was used as an analytical framework to identify salient features of argument in the speech. The transcripts of the 24 lessons were systematically analysed for components of argument identified by TAP, to ascertain the teachers' use of argumentation and to measure their progress at argumentation. The analysis of TAP provided a quantitative result in terms of the frequency and complexity of arguments captured by the audiotapes.

The second aim was to determine how teachers' oral contributions reflected their epistemic goals during argumentation lessons. To study this aspect of teachers'

development required more detailed qualitative analysis of the zoo lesson transcripts, so a decision was made to focus the analysis on a small number of contrasting cases. Using a grounded approach with the transcripts of two teachers for whom the TAP analysis had shown differing changes with argument, a coding scheme was derived that focused on the processes needed to facilitate argumentation, such as encouraging listening and prompting justification. Developed initially from the transcript of one teacher, the coding scheme was then applied to the transcripts of the other teacher to see what differences there were, if any, in the use of oral discourse to facilitate argumentation. This coding scheme was then applied to two more teachers, for whom the TAP analysis had demonstrated significant change in their use of argumentative discourse but who had selected different strategies for implementing the zoo lesson, and finally to a fifth teacher for whom there was little change in the TAP analyses. Throughout this process, the coding scheme of teacher's mechanisms for facilitating argumentation was refined and extended to include more codes. The final coding scheme was re-applied to the 10 transcripts to consistently code ways in which the teachers' oral contributions facilitated argumentation. Thus, from the initial group of 12 teachers, this detailed analysis of five teachers' transcripts provided data on teachers' oral contributions using two contrasting teacher variables: their use of argumentation (as determined by the TAP analysis), and their approach to teaching a lesson.

The following example illustrates the method of coding the transcripts using TAP as a guiding framework. For the statement "Zoos are horrible; I am totally against zoos", the focus would be on the substantive claim. In this case, the difficulty lies in the fact that both can be considered to be claims (i.e., "Zoos are horrible" and "I am totally against zoos"). The questions for the analysis then become which of these is the substantive claim and which is a subsidiary claim? Our general view is that there is inevitably a process of interpretation to be made and that some of that process is reliant on listening to the tape and hearing the persuasive force of the various statements. The judgement here was that the emphasis lies on the second part of the statement because the task context demands a reference to a particular position (for or against zoos) and that this is, therefore, the substantive claim. Our approach was always to seek to identify, through a careful reading of the transcript or by listening to the tape, what constituted the claim. Once the claim was established, the next step was the resolution of the data, warrants, and backings. Our view was that a necessary requirement of all arguments that transcend mere claims is that they are substantiated by data. Therefore, the next task was the identification of what constitutes the data for the argument, which is often preceded by words such as *because*, *since*, or *as*. The warrant, if present, was then the phrase or substance of the discourse that relates the data as evidence to the claim.

In undertaking this task, we were conscious of the methodological difficulties in using TAP as a method of determining the structure and components of an argument (Kelly, Drucker, & Chen, 1998). Reducing these difficulties was, therefore, a significant methodological challenge for our work (Osborne et al., 2004a; Erduran et al., 2004).

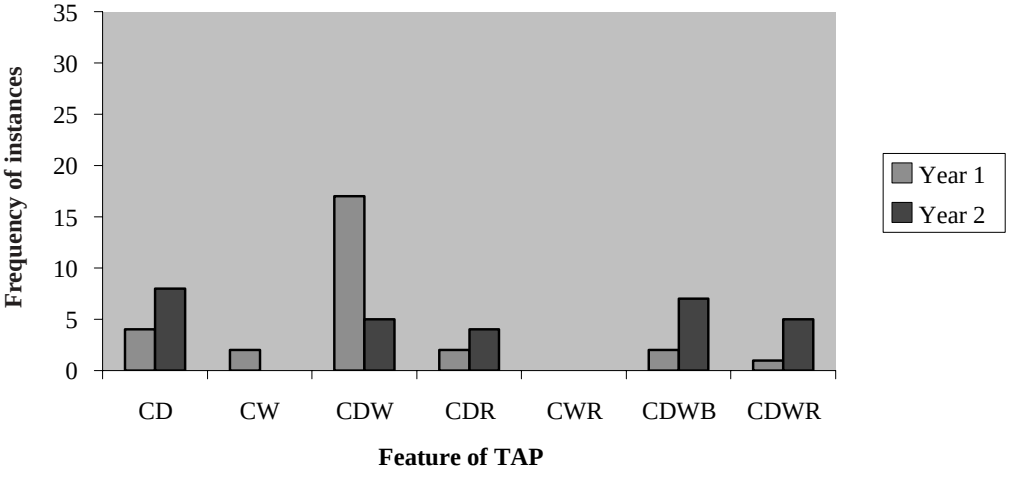


Figure 2. Sarah, Year 1 versus Year 2

Results of the TAP Analyses

Using TAP to analyse the arguments occurring in the teachers' discourse, the results provide a comparative measure of the argumentation occurring in each lesson. Typical transcript data on two teachers for the 2 years are summarized in Figures 2 and 3. The *x* axis indicates the features of TAP that were used in different combinations. For example, CD indicates those instances where a claim was coupled with data; CDWB indicates that there was a claim, data, warrant, and backing as part of one argument occurring. The *y* axis illustrates the frequency of instances that such permutations of TAP were present within the transcript. In other words, we counted

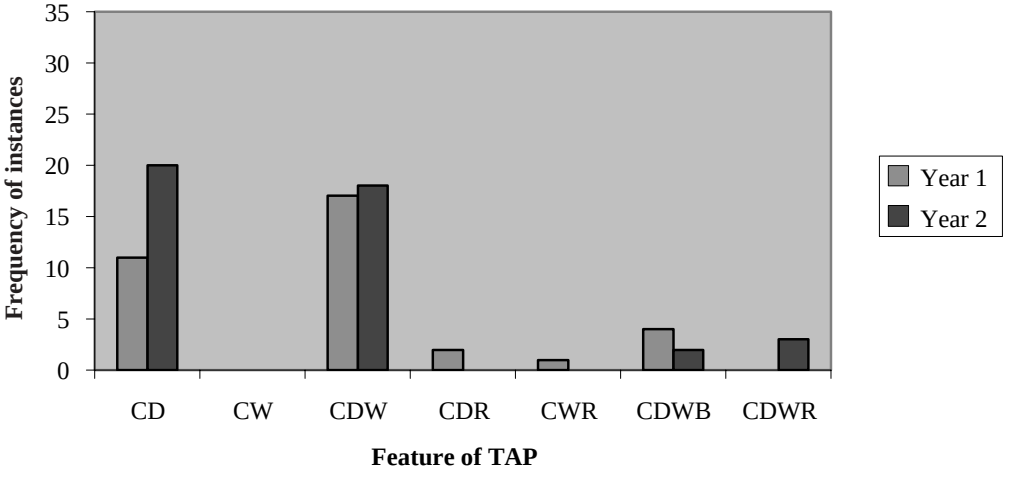


Figure 3. Matthew, Year 1 versus Year 2

the number of times each instance of TAP occurred in the data across both years for each teacher.

The figures seem to suggest several trends. First, that argumentation discourse does occur in these science lessons across both years. The figures show the extent to which the classes of these two teachers were involved in the construction of each aspect of TAP. In other words, it is possible to trace the nature of different permutations of TAP in each teacher's implementation of the lesson. The second trend is that each teacher shows a similar pattern in the occurrence of argumentation across the 2 years, with different students. This trend was identified for all 12 teachers in the study. Third, although the charts have a consistent pattern for each teacher, they are *different from each other*. This finding would suggest that there is no common pattern and that the use of argumentation is teacher dependent.

The figures also illustrate the nature of progression of each teacher across the two years. Tracing the chart from left to right on the x axis, there is an increasing complexity in the use of TAP; that is, there are more warrants, backings, and rebuttals. Thus, if there was a shift, for example, in the number of arguments of the form CD (claim–data) to more CDWB (claim–data–warrant–backing) arguments in Year 2, then this was considered to be an improvement in the nature of arguments constructed from one year to the next. Summing all the categories for all the teachers shows that the change is significant ($p < .01$, $n = 3$).[1] However, detailed analysis shows that this change was not uniform. Across all 12 teachers, significant improvements were noted for five teachers in the sample (four teachers at $p < .01$, one teacher at $p < .05$), with two teachers approaching significance at the $p < .05$ level while the other five teachers showed little, if any, change. Table 1 presents these results, where the data have been grouped into clusters according to the number of TAP features (2–4) for each argument.

Results of Teacher Discourse Analyses

To select the cases for detailed analysis, videotapes of the zoo lessons were studied alongside the lesson transcripts. David, Sarah, and Lucy (Table 1) were selected because they not only demonstrated significant changes with TAP, but also had contrasting strategies for conducting the zoo lessons. Although each of their lessons involved small group discussion based on argumentation activities, David's lessons included more argumentation episodes within whole class debate, Sarah placed more emphasis on her interactions with students in small groups, and Lucy focused on the use of role-play and whole class reflection on argument. She assigned roles to different students (e.g., politicians, local residents, zoologists, ecologists, and teachers) and organized students into pairs having opposing positions. Two further teachers (Matthew and Pamela) were selected who had shown no significant change in TAP, to see whether their oral contributions reflected the same range of argumentation goals as those of David, Sarah, and Lucy.

The analysis of the transcripts focused on teachers' oral contributions that were oriented to the facilitation of argumentation. Therefore, wherever a teacher's

Table 1. Profile of argumentation discourse for the classrooms of all the teachers from Year 1 to Year 2 as percentages

Teacher		CD, CW, CR (%)	CDW, CDR, CWR, DWB (%)	CDWB, CDWR, CDWB (%)	Significance
Jeremy	Year 1	50	44	6	
	Year 2	59	27	14	
David	Year 1	40	48	13	**
	Year 2	23	31	46	
Maureen	Year 1	37	43	20	
	Year 2	43	43	14	
Frances	Year 1	20	46	34	
	Year 2	33	39	27	
Jules	Year 1	47	43	10	**
	Year 2	22	37	41	
Patrick	Year 1	46	36	18	
	Year 2	24	55	21	
Lucy	Year 1	20	70	10	*
	Year 2	0	50	50	
Annie	Year 1	38	38	24	**
	Year 2	5	85	10	
Sarah	Year 1	21	68	11	**
	Year 2	28	31	41	
Pamela	Year 1	32	47	21	
	Year 2	40	40	20	
Jason	Year 1	36	48	16	
	Year 2	41	41	18	
Matthew	Year 1	31	57	11	
	Year 2	47	42	12	
Total	Year 1	36	48	16	**
	Year 2	31	42	27	

Note. C, claim; D, data; W, warrant; B, backing *Significant at $p < .05$, **significant at $p < .01$.

utterance reflected an implicit goal for students to achieve argumentation, it was highlighted and coded. For example, in his Year 1 lesson, David said "Right, this is a listening part now. Very important. If you are going to be able to argue you have to be able to listen to know what the other people are saying". This utterance reflected the goal of "students listening" to each other and was coded "encourages listening". Examination of the teacher utterances in the zoo lesson transcripts enabled us to identify a range of goals for facilitating the argumentation process. These oral contributions were examined for similarity in terms of the kinds of goals they represented and were coded accordingly. The codes were applied to all 10 transcripts and further categories and codes were identified that captured the range of goals implicit in the five teachers' oral contributions. The codes are shown in

Table 2. Codes and categories for argumentation processes, arranged in a tentative hierarchy

Codes for teacher utterances that reflect goals for argumentation	Categories of argumentation processes as reflected in teacher utterances
Encourages discussion	Talking and listening
Encourages listening	
Defines argument	Knowing meaning of argument
Exemplifies argument	
Encourages ideas	Positioning
Encourages positioning	
Values different positions	
Checks evidence	Justifying with evidence
Provides evidence	
Prompts justification	
Emphasizes justification	
Encourages further justification	
Plays devil's advocate	
Uses writing frame or written work/prepares presentations/gives roles	Constructing arguments
Encourages evaluation	Evaluating arguments
Evaluates arguments	
process – using evidence	
content – nature of evidence	
Encourages anticipating counter-argument	Counter-arguing/debating
Encourages debate (through role play)	
Encourages reflection	Reflecting on argument process
Asks about mind-change	

Table 2 (column 1). In this analysis we did not attempt to study the frequency of these codes, as lessons were of different lengths and structure, but focused on whether epistemic goals were apparent or not in the pedagogy and discourse (evidence type in *italics*) of the five teachers.

Talking and Listening

In order for argumentation to take place, students need to be able to work in groups, listening to each other and articulating their own ideas. For some students, this process is unfamiliar, as they are not used to working discursively in groups when the predominant classroom strategies in science are more teacher-directed (Newton et al., 1999). The previous example illustrated the goal of listening, and the following excerpt taken from David's lesson in Year 2 provides another example where he *encourages listening*:

> So we need to be able to say our own ideas and also we need to be able to listen. When you are working in groups the same thing applies. You need to be able to speak, but you also need to be able to listen. (David, Year 2)

In addition to telling students they have to listen to each other, teachers can *encourage listening* by asking students what another student said. Lucy's talk demonstrates this process:

> OK, how many bits of evidence did Sally give "for" [the zoo]? Did she just give one or did she give more than one? Tell me. Did she just give one? Or were her reasons for agreeing with building the zoo more than one? Who thinks there were more than one? [Students respond] Definitely more than one. OK, Onny, give me two things that she said for "why". Whether you agree or not, just tell me what she said. (Lucy, Year 1)

Such questioning goes further than simply telling students to listen, it actively encourages them to listen to each other's use of evidence. Lucy's practice of encouraging students to listen and articulate each others' arguments extends the dialogue beyond the common question–response–feedback pattern (Lemke, 1990) that dominates much discourse in science lessons, where teachers listen to one response, evaluate it, and move on to further questions. In asking Onny to articulate Sally's arguments, Lucy is encouraging purposeful listening, an act that many students do not display, but one that is an essential precursor to meaningful argumentation in small group formats. Many students simply talk at each other and so teachers need to highlight the value of listening.

Knowing the meaning of argument. Teachers made attempts to help students know what argument means. They would do this at a basic level by *defining argument*, such as Pamela did when she introduced her first zoo lesson by relating what the students were doing to the work of scientists:

> The way scientists come up with theories is to look at evidence that they are given, look at facts that they've got and then discuss them, argue over them and then, when they have done that they come up with what they think is a good idea. … Now we are going to be doing a series of this kind of argument, throughout this year. (Pamela, Year 1)

Teachers would also address this goal by *exemplifying argument*; for example, as David did in Year 2:

> Let me give you an example, some people say—oh, let's build a new zoo because animals that are going to be extinct, we can save them by putting them in new zoos. (David, Year 2)

Through reflecting on the process of argumentation, teachers can also aim to develop an understanding of the meaning of argument. Lucy did this towards the end of her first zoo lesson:

> When you have an argument what are you doing? Let's sum up, what is an argument and why is it a valuable thing, Naomi? (Lucy)
>
> Stating your point of view. (Naomi)

Although Naomi responds in a rather simple way, Lucy's question attempts to open up the argument space and students presenting a point of view can be a first step. Lucy's question also tries to take students beyond defining and modelling argument

towards a reflection on the value of arguments. In this way she conveys and reinforces the meaning of argument.

Positioning. In order for argumentation to proceed, there needs to be recognition that there may be different positions one can take that might lead one to make a claim. Teachers would therefore *encourage ideas* to be aired in order that students were able to see that there were choices:

> These are just your first thoughts, some of your arguments for and against. I am not asking you at this stage to decide whether you are for it or against it. Just some of your arguments for and against. (David, Year 1)

Once the choices were exposed, teachers would at some point *encourage students to take a position*, either as individuals or as a group; for example, as David did after the initial group brainstorm of ideas in Year 1:

> So you need to decide are you going to say yes, we should support building a new zoo or no, we shouldn't support building a new zoo. Then you are going to have to give your arguments. (David, Year 1)

The use of more advanced strategies, such as role-play, necessarily involve positioning. In adopting a role, students take a position and argue for it. Lucy encouraged such positioning in her role-play lesson; for example, when the ecologists were having difficulty deciding what their position was:

> OK, you are ecologists, so you would want animals to stay in their natural environment, you study animals in their natural environment, this, to you, is abhorrent; you can't believe that people do this. Taking them out. (Lucy, Year 1)

Justifying with evidence. Teachers' attempts to enhance the process of justification were common, showing they had clearly assimilated this goal within their practice. How they supported justification was categorized and coded using four different kinds of facilitation. Some teachers talked about the sources the students could draw on to *check* that they have an *evidence* base:

> So you should all have seen something about zoos now and you should have all maybe just thought about it a little bit last night, about zoos, your experience of zoos, what zoos might be like from the animal's point of view. (David, Year 1)

Pamela spent the first part of her second lesson checking the students' evidence base by spending time going through their knowledge of zoos. Both Pamela and Matthew also tended to *provide evidence* in response to students' ideas:

> Think about what we were doing in populations. What were we doing in populations? So what do things need? They need space, don't they? Yeah, OK, but what is the other problem with animals? Some species are dying out, aren't they? So they could help, couldn't they, in terms of species that are going to be extinct. Yeah? (Matthew, Year 1)

Teachers provided arguing prompts when they wanted students to add justification to their claims. Such prompts often took the form of asking "why?" or "how do

you know?". Teachers also *played devil's advocate*, as David did in the second zoo lesson, in order to stimulate further justification of arguments:

> *David*: OK, how do you know they like being out in the wild? How do you know they don't think of a zoo like—this is brilliant, I don't have to catch my food, somebody just brings it around to me.
> *Student*: They are free and they can do whatever they want to do.
> *David*: But how do you know that they don't prefer it in a zoo? (Year 2)

Constructing arguments. There were many ways in which teachers encouraged students to engage in the construction of arguments. The most straightforward way was to ask students to construct their arguments on paper using a *writing frame*, which Matthew did in both lessons. Some teachers asked students to *prepare presentations* of arguments. In role-play situations, students had to construct arguments commensurate with their roles. Lucy *gave roles* to the students and asked them to construct appropriate arguments. She did this in a structured way:

> You've got to become the person you are going to be. Just like when you are acting. This group, you are an MP in the local area, OK? This group, you are residents living very close by. OK? … You have until quarter to two to have three proposals, three reasons why you should build or not build the zoo, that you are putting forward to the agency. Only three. (Lucy)

Evaluating arguments. Some teachers had clear goals that focused on the evaluation of arguments and asked students to make judgements about exemplar arguments. In doing so, they either emphasized that having evidence is important or they focused on the nature of the evidence. In Year 1, David did both of these things. For example, in terms of the process of argument, he had one early interaction in small group discussion where he emphasized that good arguments involve the use of evidence. This kind of utterance has been coded as *evaluates argument (process)*. Later, during whole class discussion, he focused more on evaluating the nature of evidence in referring to what makes a strong argument. This has been coded as *evaluates argument (content)*.

Sarah foregrounded the evaluation of arguments strongly in her second zoo lesson. In setting up the first small group discussion, her talk modelled the process of producing a strong argument:

> *Sarah*: And we are trying to think this morning about what sorts of things will make a good argument. How are you going to persuade this agency that yes, the zoos should be opened? You need to put forward strong arguments or, if you don't want it, strong arguments against the zoo. So what sorts of things do you think you need to do to make a good argument? How are you going to make your argument strong?
> *Student*: By backing them up.
> *Sarah*: By backing them up, what do you mean by that, Emma? How can, what do you mean by backing them up?
> *Student*: You say how and why.

Sarah: Alan, I just heard a word from you, what did you say?
Student: Evidence.
Sarah: Evidence. Giving evidence to support, what, your ideas? Your views? Evidence and ideas to back it. Should it just be opinions and feelings or should it be …?
Student: Facts.
Sarah: Facts, possibly. What would probably a weak argument be? Any ideas? What might make an argument not a very good one? Would it contain evidence and backing like Emma and Alan said? [Murmurs of disagreement] No. It's …
Student: [Silly stray comments]
Sarah: Maybe it's just the comments, without actually explaining fully what you are trying to say? (Year 2)

Thus, in emphasizing and modelling evaluation, teachers are also extending the notion of what argument means, beyond defining and exemplifying.

Counter-arguing/debating. David and Sarah recognized the importance of encouraging counter-argument:

> Can anyone think of anything that somebody might say to oppose that? What might someone say which makes that argument a bit flawed? (Sarah, Year 2)

Although teachers would emphasize and encourage the process of using evidence, not all would engage in this process. For instance, Matthew discouraged counter-argument. In contrast, in setting up role-play, Lucy structured her lesson to encourage counter-argument and debate. Once her students had adopted their roles, she paired them according to opposing positions in order to counter-argue.

Reflecting on argument process. Some teachers thought it important to *encourage reflection* on the students' process of argumentation. For example, Sarah encouraged her students to reflect on the role she was taking in helping them to make better arguments:

> So have you thought about how you are going to justify it? What is your argument? You have got to really think about it. Can you see what I am doing? I am constantly saying—why? Questioning what you are saying, so you have to have every single little bit of reason and evidence to back up what you are saying. (Sarah, Year 1)

Lucy *encouraged* her students to *reflect* through asking them about any change of position they had experienced as a result of role-play. In doing so she touched on the processes of positioning, evaluating, and counter-arguing by incorporating the idea that it was legitimate to change position if you judged an opposing argument to be stronger:

Lucy: Did anybody manage to argue it so that their partner changed their mind from where they came? OK, this is the first one. Diane, would you like to explain how you persuaded Sally to change her opinion?
Diane: Well, first I found it a bit hard because Sally didn't like to see the animals cooped up in cages, but then at the end she said that she … it is not their

> habitat so they couldn't get food how they wanted. And then I said—well, if they are in the wild and say an animal got a bad leg or something, they wouldn't be able to go and catch food so then it would die. But then if it had been in the zoo, it would just be fed to them.

Lucy's oral contributions in the second year placed even more emphasis on the process of changing one's mind. She set up the small group discussion saying "I am looking for someone to be successful at changing their minds" and in the subsequent plenary asked several groups if there was a mind change. She foregrounded this process in the discourse, as for her it was a more distinctive goal in the second year.

In contrasting the lessons of these five teachers, it became apparent that there were differences in emphasis that were reflected in the teachers' oral contributions to the lessons. These differences in talk occurred not only between teachers, but also from one year to the next. Table 3 presents the occurrence of the codes for the five teachers; that is, which mechanism for facilitation each teacher used in their zoo lessons. If teachers demonstrated these codes, then they were attempting to develop the associated processes in their students' argumentation. For example, if they encouraged counter-argument, they believed this to be an important process. From the outset, Lucy, David, and Sarah valued student argument processes such as counter-argument and reflection. We have considered these processes to be of a higher order as they subsume other processes, such as listening, constructing arguments, and justification. The encouragement of lower order processes, including discussion and listening, may not be apparent in some teachers' talk as these processes may already be well established and need no explicit elaboration or encouragement. Table 3 demonstrates that Matthew and, in particular, Pamela showed a narrower range of higher order talk.

Lucy's well-developed epistemic goals are reflected in her emphasis on reasoning, debate, and reflection in both years. Her development from one year to the next is not apparent in Table 3, as it shows she had such goals from the outset, but she made these goals more explicit in her whole class teaching. Sarah also exhibited enhanced epistemic goals in both years and changed her practice to include more debate through role-play in Year 2. David also exhibited advanced goals but only reflected on argument in the first year. He did not give prominence to this in his teaching. His main change in the second year was to play devil's advocate in small group and whole class discussion, a technique that encouraged students to extend their arguments.

Table 3 illustrates that this coding system is of particular value in identifying what some teachers are *not* doing; for example, Matthew and Pamela. The table demonstrates they clearly exercised many aspects of facilitating argumentation (e.g., prompting justification), but also shows their limited appreciation of the full range of goals identified in the other teachers, such as counter-argument and reflection. Matthew and Pamela did not exhibit changes in their TAP profiles, and their use of facilitation talk likewise remained consistent. Previous analysis showed that Matthew made slight changes in his emphasis on evidence (Simon et al., 2003), but no changes were detected for Pamela. These results raise two key questions:

Table 3. Argument processes, teacher facilitation codes and occurrence of codes across 2 years for five teachers

		Lucy		David		Sarah		Matthew		Pamela	
Argument process	Codes for teacher facilitation	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Talking and listening	Encourages discussion			⋆	⋆		⋆				⋆
	Encourages listening	⋆		⋆	⋆	⋆				⋆	⋆
Knowing meaning of argument	Defines argument	⋆	⋆	⋆	⋆		⋆		⋆	⋆	
	Exemplifies argument			⋆	⋆	⋆	⋆	⋆	⋆		
Positioning	Encourages ideas	⋆		⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆
	Encourages positioning	⋆	⋆	⋆	⋆					⋆	⋆
	Values different positions		⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆
Justifying with evidence	Checks evidence		⋆	⋆	⋆		⋆	⋆	⋆	⋆	⋆
	Provides evidence					⋆	⋆	⋆	⋆	⋆	⋆
	Prompts justification	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆
	Emphasizes justification	⋆	⋆	⋆	⋆		⋆	⋆	⋆	⋆	⋆
	Encourages further justification				⋆	⋆	⋆	⋆	⋆		
	Plays devil's advocate				⋆	⋆					
Constructing arguments	Uses writing frame or written work/ prepares presentations/gives roles	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆
Evaluating arguments	Encourages evaluation			⋆	⋆	⋆	⋆	⋆	⋆		
	Evaluates arguments process – using evidence/content – nature of evidence			⋆	⋆		⋆		⋆		
Counter-arguing/debating	Encourages anticipating counter-argument			⋆	⋆	⋆	⋆				
	Encourages debate (through role play)	⋆	⋆				⋆				
Reflecting on argument process	Encourages reflection	⋆	⋆	⋆		⋆	⋆				
	Asks about mind-change	⋆	⋆								

1. Why did they not make further changes?
2. How might professional development for teachers who may have a narrow range of teaching goals be designed?

Discussion and Implications

In this paper we have presented findings from our work on developing teachers' use of argumentation in school science classrooms. The work has made progress on several fronts. First, the series of workshop meetings gave rise to a set of materials and pedagogic strategies that can be used in a structured and focused manner to facilitate argumentation in the classroom. The design of these workshop meetings—and the successful implementation of our interpretation of argument portrayed in these meetings—has provided a basis for further development in this area. Curriculum materials play a key role in initiating and sustaining change because they are "concrete, tangible vehicles for embodying the essential ideas of a reform" (Powell & Anderson, 2002, p. 112). Working collaboratively with teachers has resulted in the production of materials that they feel empowered to use and own.

Second, the workshops with teachers led to an initial change in practice for two-thirds of the group. This finding leads us to conclude that it is possible for science teachers to adapt and develop their practice in such a way as to bring about a change in the nature of classroom discourse. During the early workshops teachers expressed anxiety about presenting alternative theories to students (i.e., competing explanations for how we see objects) as they thought these may cause confusion for students and strengthen their belief in scientifically incorrect ideas; but, by the end of the year, these fears had diminished. Discussion with teachers in the final workshop showed they had come to recognize that the opportunity for students to reflect, discuss, and argue how evidence did or did not support a theoretical explanation was beneficial to students' engagement with scientific ideas.

Third, the two methodological approaches to the analysis of classroom discourse have provided us with new opportunities for helping teachers to develop the teaching of ideas and evidence in science. The use of TAP enabled us to identify arguments and assess their quality. Moreover, the features of TAP have offered teachers a language for talking about science and for understanding the epistemic nature of their own discipline. Our analysis of teachers' oral contributions has enabled us to identify the kinds of teacher talk that may enable student argumentation to proceed. Teachers who focus on the importance of talking and listening to others, conveying the meaning of argument through modelling and exemplification, positioning oneself within an argument and justifying that position using evidence, constructing and evaluating arguments, exercising counter-argument and debate, and reflecting upon the nature of argumentation begin to demonstrate implicit goals that value these aspects of argumentation. Although we have not linked the effects of these teachers' oral contributions to student outcomes, the detailed analysis of the ways in which teachers used their talk to emphasize the processes involved in argumentation

in the science classroom has informed us of possible ways in which epistemic goals may be foregrounded by teachers.

From the TAP profiles generated in this research, we have learned that teachers are different but consistent in their practice, with the changes from one year to the next being much smaller than differences between teachers. The variations between teachers and the consistent pattern of TAP for each teacher demonstrate the uniqueness of pedagogy. In addition, the variations in the degree of change demonstrated by each teacher show that progression in learning is variable. The message here—that teachers implement new ideas differently and so there are no homogeneous outcomes—reinforces the work of previous studies of professional development (Harland & Kinder, 1997). If professional development is to impact on practice, such differences need to be recognized and taken into account when designing professional development for teachers.

Our analysis of teachers' oral contributions to facilitate argumentation showed that their initial approach to implementing argumentation was not fundamentally altered, but, rather, refined or extended over the year. Some of the teachers (e.g., Lucy, David, and Sarah) demonstrated good classroom practices in the teaching of argument that were fine-tuned as a result of engagement in the project. It is possible that they had more extensive knowledge and understanding of the nature and purpose of the project, which made them more receptive to the teaching of argumentation and ownership of its aims and intentions. Matthew and Pamela showed a willingness to promote student discussion and use of evidence and, therefore, devoted lesson time to argumentation activities and supported the process of justification. However, although they demonstrated a knowledge and awareness of the epistemic goals of argumentation through their emphasis in their discourse on the importance of evidence and the importance of justifying scientific argument, they appeared not to have a full appreciation of the potential of oppositional discourse. Indeed, their oral contributions even discouraged it. Thus, our data would suggest that it is teachers' initial understanding of argumentation that determines their development, particularly in the short term. If so, this would substantiate Leithwood, Janzti, and Steinbach's (1999) argument that teachers' basic capacity for change may be dependent on their existing knowledge and understanding.

Hence, to help teachers progress in their teaching of argumentation, our data would suggest that the focus of professional development should be on teachers' existing understanding of the importance of evidence and argument in science and on their implicit goals of teaching and learning science. To this end, the research has helped to identify a tentative hierarchy of student argumentation processes, reflected within teachers' argumentation goals (Table 3), that we believe will help teachers to transform knowledge of the argumentation process into classroom discourse. Students need to learn how to listen and talk, justify claims, and so on, before they can debate; likewise, teachers need to value and learn how to implement group discussion and prompt justification before they can orchestrate effective counter-argument within their teaching.

Finally, we have found that developing the ability to understand and implement argumentation required the important process of reflection on previous experience. It is this that initiates the process of reflection-in-action, or reframing (Munby et al., 2000; Munby & Russel1, 1992; Schon, 1987)— the process that helps teachers to construct new pedagogical understanding—in this case, of argumentation and its value for learning science.

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Note

1. Significances were calculated using chi-square tests based on the frequency of arguments within each category across the 2 years (Table 1). Categories were collapsed into arguments with two elements, arguments consisting of three elements, and arguments consisting of four elements.

References

Adey, P. S., Shayer, M., & Yates, C. (2001). *Thinking science* (3rd ed.). London: Nelson Thornes.

Alvermann, D. E., & Hynd, C. R. (1986). Effects of prior knowledge activation modes and text structure on nonscience majors' comprehension of physics. *Journal of Educational Research, 83,* 97–102.

Bay, J. M., Reys, B. J., & Reys, R. E. (1999). The top 10 elements that must be in place to implement standards-based mathematics curricula. *Kappan, 80,* 503–512.

Bereiter, C., & Scardamalia, M. (1987). *The psychology of written composition.* Hillsdale, NJ: Lawrence Erlbaum.

Black, P., Harrison, C., Lee, C., Marshall, B., & Wiliam, D. (2002). *Working inside the black box.* London: King's College London.

Black, P., Harrison, C., Lee, C., Marshall, B., & Wiliam, D. (2003). *Assessment for learning: Putting it into practice.* Maidenhead, England: Open University Press.

Donnelly, J., Buchan, A., Jenkins, E., Laws, P., & Welford, G. (1996). *Investigations by order: Policy, curriculum and science teachers' work under the Education Reform Act.* Nafferton, England: Studies in Science Education.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science.* Buckingham, England: Open University Press.

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

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*(6), 915–933.

Fullan, M. (1991). *The new meaning of educational change* (2nd ed.). London: Cassell.

Fullan, M. (2001). *The new meaning of educational change* (3rd ed.). London: Routledge-Falmer.

Harland, J., & Kinder, K. (1997). Teachers' continuing professional development: Framing a model of outcomes. *British Journal of In-Service Education, 23*(1), 71–84.

Hoban, G. F. (2002). *Teacher learning for educational change.* Buckingham, England: Open University Press.

Hogan, K., & Maglienti, M. (2001). Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. *Journal of Research in Science Teaching, 38*(6), 663–687.

Hynd, C. R., & Alvermann, D. E. (1986). The role of refutation text in overcoming difficulty with science concepts. *Journal of Reading, 29*(5), 440–446.

Hynd, C. R., Alvermann, D. E., & Qian, G. (1997). Preservice elementary school teachers' conceptual changes about projectile motion: Refutation text, demonstration, affective factors and relevance. *Science Education, 81,* 1–27.

Jiménex-Aleixandre, M. P., Rodríguez, A. B., & Duschl, R. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education, 84*(6), 757–792.

Jones, A., Simon, S., Black, P., Fairbrother, R., & Watson, J. R. (1992). *Open work in science: Development of investigations in schools.* Hatfield, England: Association for Science Education.

Joyce, B., & Showers, B. (1988). *Student achievement through staff development.* White Plains, NY: Longman.

Kelly, G. J., Drucker, S., & Chen, K. (1998). Students' reasoning about electricity: Combining performance assessment with argumentation analysis. *International Journal of Science Education, 20*(7), 849–871.

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

Leithwood, K., Jantzi, D., & Steinbach, R. (1999). *Changing leadership for changing times.* Buckingham, England: Open University Press.

Lemke, J. L. (1990). *Talking science: Language, learning and values.* Norwood, NJ: Ablex Publishing.

Loucks-Horsley, S., Hewson, P., Love, N., & Stiles, K. E. (1998). *Designing professional development for teachers of science and mathematics.* Thousand Oaks, CA: Corwin Press.

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

Minstrell, J., & Van Zee, E. (Eds.). (2000). *Teaching in the inquiry-based science classroom.* Washington, DC: American Association for the Advancement of Science.

Mortimer, E., & Scott, P. (2003). *Meaning making in secondary science classrooms.* Maidenhead, England: Open University Press.

Munby, H., & Russell, T. (1992). Transforming chemistry research into teaching: The complexities of adopting new frames for experience. In T. Russell & H. Munby (Eds.), *Teachers and teaching: From classroom to reflection* (pp. 90–108). London: Falmer Press.

Munby, H., Cunningham, M., & Lock, C. (2000). School science culture: A case study of barriers to developing professional knowledge. *Science Education, 84,* 193–211.

National Research Council. (2000). *Inquiry and the national science education standards.* Washington, DC: National Academy Press.

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education, 21*(5), 553–576.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87,* 224–240.

Ogborn, J. (2002). Ownership and transformation: Teachers using curriculum innovation. *Physics Education, 37*(2), 142–146.

Osborne, J., Erduran, S., & Simon, S. (2004a). Enhancing the quality of argument in school science. *Journal of Research in Science Teaching, 41*(10), 994–1020.

Osborne, J., Erduran, S., & Simon, S. (2004b). *Ideas, evidence and argument in science* [In-service Training Pack, Resource Pack and Video]. London: Nuffield Foundation.

Pogrow, S. (1996). Reforming the wannabe reformers: Why education reforms almost always end up making things worse. *Kappan, 77,* 656–663.

Pontecorvo, C. (1987). Discussing and reasoning: The role of argument in knowledge construction. In E. De Corte, H. Lodewijks, R. Parmentier, & P. Span (Eds.), *Learning and instruction: European research in an international context* (pp. 239–250). Oxford, England: Pergamon Press.

Powell, J. C., & Anderson, R. D. (2002). Changing teachers' practice: Curriculum materials and science education reform in the USA. *Studies in Science Education, 37,* 107–136.

Rivard, L. P., & Straw, S. B. (2000). The effect of talk and writing on learning science: An exploratory study. *Science Education, 84,* 566–593.

Russell, T. L. (1983). Analysing arguments in science classroom discourse: Can teachers' questions distort scientific authority? *Journal of Research in Science Teaching, 20,* 27–45.

Schon, D. (1987). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions.* San Francisco: Jossey-Bass.

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

Shayer, M., & Adey, P. (Eds.). (2002). *Learning intelligence.* Buckingham, England: Open University Press.

Simon, S., Osborne, J., & Erduran, S. (2003). Systemic teacher development to enhance the use of argumentation in school science activities. In J. Wallace & J. Loughran (Eds.), *Leadership and professional development in science education: New possibilities for enhancing teacher learning* (pp. 198–217). London and New York: RoutledgeFalmer.

Spillane, J. S. (1999). External reform initiatives and teachers' efforts to reconstruct their practice: The mediating role of teachers' zones of enactment. *Journal of Curriculum Studies, 31*(2), 143–175.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37*(9), 963–980.

Sutton, C. (1992). *Words, science and learning.* Buckingham, England: Open University Press.

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

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35–62.

Appendix A. Stimulus used for argumentation in a socio-scientific context—the zoo lesson

International Agency
for Public Funding
London,
Great Britain

31 March 2000

Dear Student,

I am pleased to invite you to take part in a new project that will take place at your school. We are currently asking students to let us know if our agency should fund the opening of a new zoo.

Some people believe that zoos should be banned. Others think that zoos serve a good role in our society. We need your help in deciding whether or not we should provide financial support for a new zoo.

Your job as a class is to *provide arguments for or against the funding of the new zoo. There is no right or wrong answer for this project. It is important, however, that you provide reasons and evidence to support the claims you are making*.

As a reward for successfully finishing this work, you will receive a certificate and you will become an honorary member of the International Agency for Public Funding.

I hope that you will enjoy your task. I look forward to reading your reports.

Yours sincerely,

Dr. M. Smith
Director

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