Planning science instruction: from insights to learning to pedagogical practices

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Abstract

This paper sets out an approach to conceptualizing, planning and implementing science instruction, based on a sociocultural perspective, which recognizes the central importance of carefully identifying learning goals during the different phases of a teaching sequence and addressing these through different kinds of classroom talk. Two key planning tools are introduced. Firstly there is the concept of learning demand (Leach and Scott, 2002) which provides a way of identifying the nature of the intellectual challenges involved in coming to understand specific aspects of scientific conceptual knowledge. Secondly there is the concept of communicative approach (Mortimer and Scott, 2003) which allows the specification of different kinds of classroom discourse. How this approach to planning science instruction might appear in practice, and the impact of the instruction on science learning, will be illustrated through reference to a recently completed research project (Millar et al. in press).

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1. Introduction

Throughout their professional lives science teachers face the challenge of planning science instruction. On a daily basis, decisions are made on how best to use the limited periods of time which constitute science lessons. A rather fundamental question to pose, therefore, concerns whether or not there are some approaches to planning science instruction which might be more effective, in promoting student learning, than others. The aim of this paper is to provide an argument for conceptualizing the planning of science teaching in a particular way with the focus on teaching and learning scientific conceptual knowledge. This approach draws upon a range of theoretical perspectives and has been used in planning and implementing science teaching in high school contexts in the UK. Evaluation data relating to this application of the approach are presented later in this article.

In their influential paper *Choreographies of Teaching: Bridging Instruction to Learning*, Oser and Baeriswyl (2001) argue compellingly for the need to make learning the primary focus in instructional design and therefore to design teaching explicitly to support learning. In their terms (Oser and Baeriswyl, 2001, p. 1032), ‘a choreography of teaching is composed of the planning and processing of teaching (sight structure) and of the planning and processing of the learning process (basis model) in the classroom’. The *sight structure* consists of the visible activities of the classroom, whilst the basis model refers to the underlying learning processes which are (hopefully) prompted in students. Oser and Baeriswyl (2001) argue that all too often teaching is not planned to address and to support specific aspects of learning. In such situations, they suggest that, ‘a creative ordering of visible (teaching) structures without guaranteeing the possibility of basis-model sequences is like didactic theatre. Learning and learning sequences are not the focus, instruction is’ (p.1048).

The approach to instructional design which is developed here shares this basic commitment of designing instruction to support learning. This paper offers a theoretically based, and science-teaching practice informed, approach to making a bridge from learning to teaching, moving from insights to learning to instructional design. Throughout the paper, at each stage of the process, the approach is exemplified through reference to the specific context of teaching and learning about simple electric circuits. The first part of the argument involves establishing a theoretical perspective on what is involved in learning scientific conceptual knowledge.

2. What is involved in learning scientific conceptual knowledge?

The perspective on learning outlined in this paper has been presented in detail elsewhere (Leach and Scott, 2003) and is based on Vygotskian and neo-Vygotskian views (Vygotsky 1987; Bakhtin 1981; Wertsch 1985; Scott, 1998).

Central to Vygotsky's perspective on development and learning is the assumption that higher mental functioning in the individual derives from social life (Vygotsky, 1978, p.128). In the first instance language and other semiotic mechanisms (such as mathematical symbols, diagrams, gesture, stance: see Kress et al, 2001; Lemke, 1990) provide the means for ideas to be talked through and communicated on the social or intermental plane and following the process of internalization, language and the other semiotic modes provide the tools for individual thinking. In this way talk and thought are portrayed as being intimately related.

In analysing the thematic *content* of language and thought, Vygotsky (1987) distinguishes between 'spontaneous' (or 'everyday') concepts and 'scientific' concepts. Spontaneous concepts are taken as those which are learned without conscious attention, through normal day-to-day interactions, whilst scientific concepts are those formal concepts which originate in particular disciplines (such as physics or history or psychology) and which can only be learned through instruction. This differentiation of the content of talk and thought has been elaborated by Bakhtin (1986), who refers to the different *social languages* used by specific communities of people for particular purposes. For Bakhtin, a social language is, 'a discourse peculiar to a specific stratum of society (professional, age group etc.) within a given system at a given time' (Bakhtin, 1981, p.430).

Wertsch (1991, pp.93-118) draws upon the concepts of 'social language' and 'speech genre' in suggesting that they make up a *tool kit* of ways of talking and knowing which can be drawn upon by individuals, as is appropriate, in different contexts. Thus, the different social languages and speech genres which are introduced and rehearsed on the social plane of the school classroom (relating to history, geography, science or whatever) offer the means for students to develop a range of distinctive modes of talking, thinking and knowing about the world.

According to this perspective, scientific knowledge itself is portrayed as a social language. It is based on specific concepts such as energy, mass and entropy, it involves the development of models which provide an account of phenomena in the natural world, and it is characterised by key epistemological features such as the development of theories, which can be generally applied to a whole range of phenomena and situations. It is not, however, the case that 'anything goes' in relation to the ways in which scientists talk and think about the natural world. The theories and laws of science are always constrained by the requirement to map onto observations and measurements of that natural world. It is clear that scientific knowledge is not there 'to be seen' in the material world. Learners will not stumble upon (or 'discover') the conventions, theories and practices of the scientific community without being introduced to them through teaching.

Furthermore, the science which is taught in school focuses on particular concepts and models and is subject to social and political pressures, which are quite different from those of professional science (Tiberghien, 1996). From this point of view learning science involves learning the social language of 'school science' (Leach and Scott, 2002; Mortimer and Scott, 2003).

Following this line of argument, the key question to be addressed here concerns the ways in which conceptualizing science learning as learning the social language of school science might provide a helpful starting point in identifying the *nature* of the learning involved in coming to understand specific points of school science conceptual knowledge and how that learning might be addressed through appropriate instruction.

3. The concept of learning demand

The point has been made that different *social languages* (Bakhtin, 1986) are used by specific communities of people for particular purposes. Thus a distinction can be drawn between the 'everyday' social language of day-to-day living and the 'scientific' social language which is first formally introduced in school.

From birth, each one of us is immersed in an everyday social language, which has itself been shaped by the ways in which human beings perceive their environment. It is this language which provides the means for communicating with others, it provides a way of talking and thinking about the physical and social worlds that surround us. In a strong sense, everyday social language acts to *shape* our view of the surroundings, drawing attention to particular features and presenting those features in particular ways. The informal or spontaneous (Vygotsky 1987) concepts which constitute everyday social language include many of those which are referred to as 'alternative conceptions' in the science education literature. Notions of 'plants feeding from the soil' and 'energy getting used up' are examples of everyday ways of thinking and talking, which are part of an everyday social language. Other 'alternative conceptions' are better viewed as products of school science learning: a social language emerges amongst science learners that draws upon features of everyday social language and the social language of school science, but which is different from both. From the perspective on learning taken in this paper, it is clear that it is the formal concepts of the natural sciences which provide the 'alternative' perspective to the omnipresent 'everyday' ways of talking and thinking (rather than the other way round).

The concept of 'learning demand' (Leach and Scott, 2002) offers a way of appraising the *differences* between the social language of school science and the everyday social language which learners bring to the classroom. The purpose of identifying learning demands is to bring into sharper focus the nature of the intellectual challenges facing learners as they address a particular aspect of school science; teaching can then be designed to focus on those learning demands.

An important point relating to the operationalisation of the concept of learning demand, is that a learning demand can be identified for a *group* of learners working within a specific area of scientific content. This follows from the fact that learners are immersed in a common social language in day-to-day living and will therefore arrive in school with largely similar points of view. In this respect the concept of learning demand is linked more closely to differences between social languages and the meanings that they convey, than to differences in the ‘mental resources’ of individuals. Thus, learning demands are essentially *epistemological* rather than *psychological* in nature (Leach and Scott, 2003).

3.1 Specifying learning demands

How might the learning demands for a particular conceptual area of science be specified? Three ways are presented here to identify possible differences between everyday and school science perspectives. These relate to differences in the *conceptual tools* used, differences in the *epistemological underpinning* of those conceptual tools, and differences in the *ontology* on which those conceptual tools are based.

For example, in the context of teaching and learning about air pressure, students typically draw upon the everyday concept of ‘suction’ in explaining phenomena, whilst the scientific point of view is based upon differences in air pressure. There is a difference here in the *conceptual tools* used. In relation to plant nutrition, students commonly draw upon everyday notions of ‘food’ as something that is ingested, in contrast with scientific accounts which describe the synthesis of complex organic molecules within plants, from simple, inorganic precursors.

Other differences relate to the *epistemological underpinning* of the conceptual tools used. For example, ways of generating explanations using scientific models and theories that are taken for granted in school science, are not part of the everyday social language of many learners (Vosniadou, 1994; Driver, Leach, Millar and Scott, 1996; Leach, Driver, Scott and Wood-Robinson, 1996). Thus, there is evidence that students, through their everyday social language, tend not to draw upon the epistemological principle of *consistency* that is an important feature of school science.

Learning demands may also follow from differences in the *ontology* of the conceptual tools used (Chi 1992; Chi, Slotta and deLeeuw, 1994; Vosniadou, 1994). Thus, entities that are taken for granted as having a real existence in the realm of school science may not be similarly referred to in the everyday language of students. For example, there is evidence that many lower secondary school students learning about matter cycling in ecosystems do not think about atmospheric gases as a potential source of matter for the chemical processes of ecological systems (Leach et al., 1996). There is a learning issue here which relates to the students' basic commitments about the nature of matter – initially they do not consider gases to be substantive.

In these ways the concept of learning demand allows us to specify the nature of the learning involved in coming to understand specific school science conceptual knowledge, by analyzing the differences between everyday and school science social languages. No doubt, this approach to specifying learning demands can be further extended and elaborated, but the crucial feature here is that the focus is on *differences* between social languages rather than simply on the key features of the school science concepts.

If the differences between school science and everyday ways of reasoning are great, because there is only a small overlap between the concepts and associated epistemologies and ontologies of school science and everyday views, then the school science topic in question appears difficult to learn and to teach. There is a *big* learning demand. Conversely, if the school science and everyday views are similar, the learning demand is *small* and students may think that the school science account is 'easy' or 'obvious'.

This form of analysis in terms of learning demands has absolutely fundamental implications for instructional design. Put simply, if there are big differences between the accounts offered by everyday and school science social languages, then significant instructional time and effort will be needed to support students in coming to recognize the limited overlaps and points of difference between the two views. Instructional time and effort will be needed to render the scientific point of view *plausible* to students against the backdrop of everyday thinking. Conversely if the learning demand is small, teaching and learning can be taken at a much quicker pace.

3.2 General approach to specifying learning demands

Following the ideas set out above, a general approach to identifying the learning demands for teaching and learning a specific science topic can be seen to involve the following:

1. Identify the *school science* knowledge to be learned;
2. Consider how this school science knowledge is conceptualised in the *everyday* reasoning of students;
3. Identify the *learning demand* by appraising the nature of any differences (conceptual, epistemological, ontological) between 1 and 2;

3.3 Electric circuit: Learning demand analysis

Consider now how this approach might work out in the context of teaching and learning about simple electric circuits.

Step 1: School science knowledge to be learned

Let us suppose that we are interested in introducing the basic elements of a simple conceptual model for an electric circuit, and that this model is based on the idea of energy transfer via an electric current where:

- the electric current consists of a flow of charge;
- the charges are set in motion by the battery;
- energy is transferred to the surroundings when charges pass through any resistance in the circuit.

Step 2: Students' everyday reasoning about electrical circuits

The literature (see, for example: Psillos, 1998; Shipstone, 1988) on teaching and learning about simple electric circuits points to the following characteristic patterns in students' reasoning:

- The electric circuit is not viewed as a *whole system*, with changes occurring virtually simultaneously in all parts (for example, when a switch is closed charges are set into motion in all parts of the circuit together). Instead, students often explain effects in terms of *sequential* models, where any disturbance travels in one direction and affects circuit components in succession. This is a form of linear causal reasoning (Perkins and Grotzer, 2005), such that when an extra resistive component (perhaps a bulb) is added in series to a circuit, students often predict that the 'first component' after the battery gets most, or all, of the energy.

- Students often think about electric circuits in terms of a *source* (the battery) and a *consumer* (for example, a bulb). This can lead to problems in that:
    - the charge which constitutes an electric current is considered to originate in the battery (the *source*).
    - the battery is considered to provide a fixed electric current.
    - when an extra battery is added to a circuit the extra current is thought to come from the additional battery (the *source*).
    - electric current and energy are not differentiated, with students suggesting that the current is used up in a bulb (the *consumer*).

In relation to broader epistemological issues, it is likely that the students will have little (or no) knowledge of what we mean by a scientific model of an electric circuit and little (or no) experience of moving between the 'theoretical world' of the model (based on the abstract concepts of charge, current and energy) and the 'real world' of observations and measurements (Tiberghien, 1996). In addition, students are likely to have a limited appreciation of the fact that scientific models can be applied generally to a wide range of contexts (Driver et al., 1996).

Step 3: Identification of learning demands

By comparing the school science and everyday accounts of the electric circuit, the key learning shift for the student involves moving:

from **a battery-as-source perspective:**

- the circuit is initially empty and fills with a 'substance-like material' that eventually reaches the bulb and causes it to light.
- students use a 'linear causal' pattern of reasoning

to **an all-at-once perspective:**

- when the circuit is completed the charges present are set in motion in all parts simultaneously
- students need to use 'cyclic causal' reasoning in which causes and effects co-occur (Perkins and Grotzer, 2005)

Furthermore, in developing this understanding of this school science model, the students must come to:

- develop abstract scientific concepts of charge, current, resistance and energy in the context of explaining the behaviour of simple electric circuits.
- understand that the battery is the source of energy for the circuit.
- understand that energy is transferred in the circuit whilst the current is conserved.
- understand that the charges originate in the circuit and not in the battery.
- understand that the electric circuit model based on concepts of charge, current, resistance, energy can be used to predict and explain the behaviour of a wide range of simple circuits.

Each of these points involves a conceptual issue apart from the final element which relates to more general epistemological matters.

4. The proposed steps in learning

In the previous section an approach, based on the concept of learning demand, has been set out to identify the nature of the learning involved in coming to understand specific science concepts. The next phase in this approach to planning science instruction involves identifying the general *steps in learning* (Oser and Baeriswyl, 2001) which need to be taken by students in coming to a *meaningful* understanding of that scientific conceptual knowledge. The key point to bear in mind here is that the focus is on steps in *learning* and not on teaching approaches – that comes next. Furthermore, meaningful learning is taken as involving the development of a clear grasp of the school science point of view and an understanding of how it articulates with related school science concepts and everyday understandings.

Starting from the sociocultural perspective on learning set out earlier, and thinking in *general* terms, it seems reasonable to suggest that meaningful learning of scientific conceptual knowledge should involve the following general learning steps to be taken by the students:

1. Engaging with the problem: where the student becomes motivated to engage intellectually with the ongoing instruction.
2. Working on the interface between everyday and school science views.
3. Developing, and internalizing, the school science point of view, attending to the key differences from everyday views.

4. Working with the school science point of view.
5. Applying, and expanding upon the use of, the school science point of view.

These five steps involve a progressive passage towards an independent, unassisted performance by the student in relation to the understanding and use of specific conceptual knowledge.

Perhaps not surprisingly, these general learning steps are similar to those proposed by Oser and Baeriswyl (2001, p.1054) who suggest 5 learning steps in the trajectory of a complex concept building process: 1. Direct or indirect stimulation of the awareness of what the learner already knows regarding the new concept 2. Introduction of and working through of a prototype as a valid example of the new concept 3. Analysis of essential categories and principles that define the new concept (positive and negative distinctions) 4. Active dealing with the new concept (application, synthesis and analysis) 5. Application of the new concept in different contexts (incorporation of different but similar concepts into a more complex knowledge system). One important point of difference, however, concerns the lack of emphasis which Oser and Baeriswyl place on working through the *differences* between everyday and school science views, which is key to the approach offered here.

How are these *general* learning steps to be operationalised in specific areas of science concept learning? Is it the case that these steps apply in the same way to learning in all science concept areas? The key point to consider here concerns the relationship between everyday and school science views. Returning to the concept of learning demand, it is important to recognize that learning in different content areas of science involves different kinds of demand and that this, in turn, has implications for the relative importance of the learning steps specified above.

For example, if the everyday and school science views are very similar, then ‘working on the interface between everyday and scientific points of view’ will not be a significant learning step. A practical example of this can be found in the context of teaching and learning the concept of ‘speed’. Here, students arrive in class with a strong sense of the fact that bicycles and motor cars are moving at a high speed when they cover a certain distance in a short period of time and learning steps 3, 4 and 5 assume more importance in developing the scientific formalisms of speed (perhaps in calculating speeds) and applying these in familiar and new contexts.

On the other hand, if there are considerable differences between everyday and school science views, then ‘working on the interface between everyday and scientific points of view’ becomes a highly significant learning step. One example of this would be in the teaching and learning of special relativity, where everyday assumptions about the absolute nature of time and space are directly challenged. Here, from a learning point of view the student needs to be able to recognize the differences between Newtonian and relativistic perspectives and to see how they articulate, one with the other. Coming to a meaningful understanding of special relativity therefore involves the student in comparing and contrasting the two perspectives. In such a way, learning steps 2 and 3 are woven together as the scientific point of view is developed.

The key point to recognise here, in the overall instructional design process, is the importance of interpreting and operationalising the *general* learning steps in relation to the *specific* learning demands of a given science topic.

4.2 Electric circuit: proposed learning steps

Given the significant differences between the battery-as-source everyday view of the electric circuit and the all-at-once school science perspective, set out in the learning demand analysis, it is clear that students need to spend time in working on the interface between, these contrasting models (step 2). Furthermore, the analysis of learning demands points to key issues (such as coming to understand that the charges originate in the circuit and not in the battery) which must be addressed by the students in developing and internalizing the school science point of view (step 3). Finally, it is important that the students have the opportunity to work with, and to talk through, the school science electric circuit model in familiar contexts (step 4) and then to apply it in a range of different situations (step 5).

5. Bridging from learning to teaching: the teaching interventions

Having identified five learning steps which apply to learning scientific conceptual knowledge, the next part of the argument concerns how these general learning steps can be used as a basis for developing a workable instructional sequence.

In broad terms the overall instructional sequence (consisting of a number of lessons) can be conceptualized as a series of linked *teaching interventions*, with one or more teaching interventions addressing a specific learning step. For example, the third learning step ‘Developing, and internalizing, the school science point of view’, might involve 2 or 3 teaching interventions each one designed to address a *specific learning goal*. In the context of teaching and learning about simple electric circuits a specific learning goal might be for the student to understand that current is conserved in the circuit. A second learning goal might be to understand that energy is transferred at any resistive point in a circuit. Each learning goal, which is derived from the learning demand analysis, is addressed through a specific teaching intervention. This relationship between general learning steps, specific learning goals and teaching interventions can be represented:

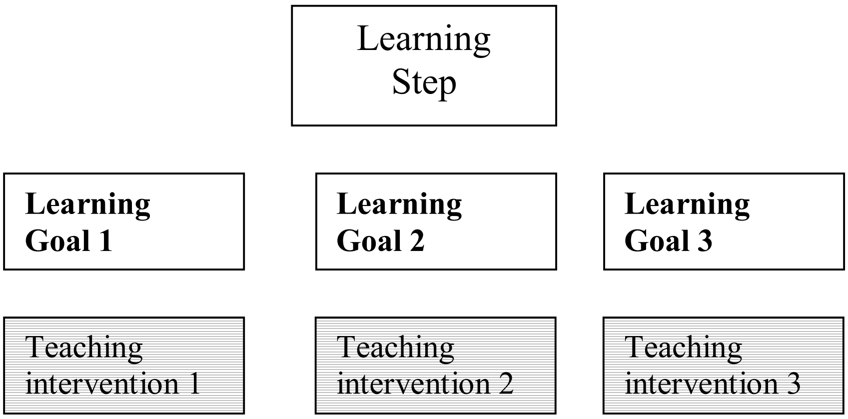

Fig 1: Learning goals and teaching interventions

5.1: Re-conceptualizing teaching interventions

Experience has shown that in high school science lessons in the UK, teaching interventions are usually associated with some kind of *activity*. Thus lesson planning might specify that the students engage in *this* experimental activity or that the teacher will perform *that* demonstration and so on. In this way the instructional activity often becomes the raison d’etre of the lesson, with the very real possibility that limited explicit links are made to specific learning goals.

The approach taken here is different. Each teaching intervention is seen not in terms of what the students will be doing but more fundamentally in terms of how the intervention can support the ongoing flow of teacher and student discourse as it is acted out on the social plane of the classroom. For example, a specific teaching intervention might involve exploring students' existing ideas about a particular phenomenon (as part of Learning Step 2). Here an activity is required which will enable active dialogue between students and between teacher and students. Later in the instructional sequence a teaching intervention might focus upon developing the school science point of view (as part of Learning Step 3). Here, the teacher might make an authoritative statement of the school science view with the help of a demonstration activity. As the instructional sequence proceeds each teaching intervention contributes to the development of the pedagogical story and there are changes in the nature of the discourse as it moves between *dialogic* consideration of different points of view to more *authoritative* approaches, focusing on the school science view. In this way, each teaching intervention is associated with a particular *communicative approach* (Mortimer and Scott, 2003), giving rise to 'rhythmic' changes in the nature of the discourse as a teaching sequence proceeds from learning step to learning step. The concept of communicative approach is considered in greater detail in the next section.

Taking these ideas together, any *teaching intervention* can be conceptualized in terms of four linked aspects:

1. Learning step: one of the five steps specified.
2. Specific learning goals: derived from the learning demand analysis and specifying the key content themes to be addressed
3. Communicative approach: specifying how the discourse of the social plane is to be enacted.
4. The instructional activity: for example, a demonstration, experiment, group discussion, lecture and so on.

Putting all of these ideas together, the overall approach to planning science instruction involves the following passage from consideration of learning issues to the development of instructional approaches:

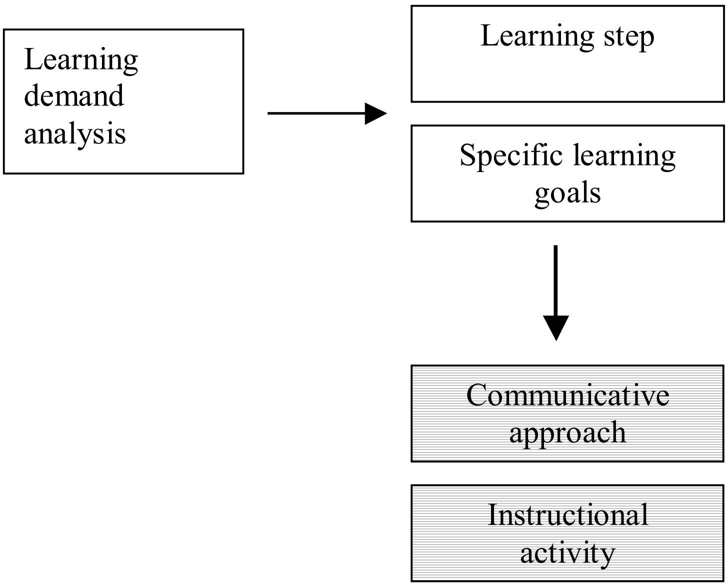

Fig 2: Overall approach to instructional design

Returning to the work of Oser and Baeriswyl (2001), the learning step and specific learning goals relate to their notion of the *basis model*, whilst the combination of communicative approach and instructional activity link to the *visible structure* of the lesson.

5.2: The concept of communicative approach

The concept of Communicative Approach was first developed by Mortimer and Scott (2003), and provides a perspective on *how* the teacher communicates with students to develop ideas in the classroom. Thus, the communicative approach focuses on questions such as whether or not the teacher interacts with students (either taking turns in the discourse or simply presenting material), and whether the students' ideas are taken into account as the lessons proceed. Four fundamental classes of communicative approach have been identified (Mortimer and Scott, 2003, p. 34) and these are defined by characterising the talk between teacher and students along each of two dimensions, *dialogic-authoritative* and *interactive-non interactive*.

The dialogic-authoritative dimension

The distinction between authoritative and dialogic functions has been discussed by Wertsch (1991), and was used by Mortimer (1998) in analysing discourse from a Brazilian classroom. It is based on the notions of authoritative and internally persuasive discourse, as outlined by Bakhtin (1981), and on the functional dualism of texts introduced by Lotman (1988) (quoted by Wertsch, 1991, p. 73-74). Following on from these perspectives, dialogic discourse is defined as being that which is open to different points of view.

At different points in a sequence of science lessons dialogic talk inevitably takes on a different character. Thus at the start of a lesson sequence, a teaching intervention might allow students to explore their everyday views about a particular phenomenon (Learning Step 2). Later on in the sequence, the students might discuss (bringing different points of view) how to apply a newly-learned scientific idea in a novel context (Learning Step 5). In these ways dialogic discourse is open to different perspectives. There is always the attempt to acknowledge the views of others, and through dialogic discourse the teacher attends to the students' points of view as well as to the school science view.

By way of contrast, *authoritative* discourse allows for no bringing together and exploration of ideas. Here the teacher focuses attention on the school science point of view. If ideas or questions, which do not contribute to the development of the school science story, are raised by students they are likely to be reshaped or ignored by the teacher. Alternatively, if a student idea is perceived by the teacher as being helpful to the development of the scientific story it is may be seized upon and used. In these ways authoritative discourse is *closed* to the points of view of others, with its direction having been set in advance by the teacher. More than one voice may be heard, through the contributions of different students, but there is no exploration of different perspectives, and no explicit interanimation of ideas, since the student contributions are not taken into account by the teacher unless they are consistent with the developing school science story.

The interactive-non interactive dimension

An important feature of the distinction between dialogic and authoritative approaches is that a sequence of talk can be dialogic or authoritative in nature, independent of whether it is uttered individually or between people. What makes talk functionally dialogic is the fact that different ideas are acknowledged, rather than whether it is produced by a group of people or by a solitary individual. This point leads us to the second dimension to consider in thinking about the Communicative Approach: that the talk can be *interactive* in the sense of allowing for the participation of more than one person, or *non-interactive* in the sense of excluding the participation of other people.

Four classes of communicative approach

Combining the two dimensions, any episode of classroom talk can be identified as being either *interactive* or *non-interactive* on the one hand, and *dialogic* or *authoritative* on the other. This combining of the two dimensions can be represented in the following way:

	INTERACTIVE	**NON-INTERACTIVE**
DIALOGIC	***A. Interactive / Dialogic***	***B. Non-interactive / Dialogic***
AUTHORITATIVE	***B. Interactive / Authoritative***	***C. Non-interactive/ Authoritative***

Fig 3: Four classes of communicative approach

The four classes, as they appear in the classroom, can be exemplified as follows:

- **a. Interactive/dialogic:** teacher and students consider a range of ideas.
- **b. Non-interactive/dialogic:** teacher revisits and summarises different points of view.
- **c. Interactive/authoritative:** teacher focuses on one specific point of view and leads students through a question and answer routine with the aim of establishing and consolidating that point of view.
- **d. Non-interactive/authoritative:** teacher presents a specific point of view.

These four classes of communicative approach provide a tool for specifying the nature of the communication in any teaching intervention. Although the concept of communicative approach was first developed in relation to teacher-student interactions, it can also be applied to student-student interactions.

5.3: Electric circuit: teaching interventions

Returning to the electric circuit example, consider now how the first two teaching interventions of a lesson sequence might be developed.

Teaching intervention 1: The BIG circuit!

The argument was made earlier that in this context there are significant differences between the everyday and school science views and that the Learning Step of 'working on the interface between everyday and school science views' needs to be addressed.

Specific learning goals

The learning demand analysis points to the prominence of the 'battery-as-source' model in students' everyday thinking. Specific learning goals for this intervention are therefore for students to:

1. recognise the nature of the battery-as-source model and its shortcomings in accounting for the behaviour of simple circuits.
2. become motivated to think about an alternative way of accounting for the behaviour of simple circuits.

Communicative approach

An interactive/dialogic communicative approach allows students to make explicit their views about the working of simple circuits.

Instructional activity

The BIG circuit teaching intervention was developed to address the specific learning goals outlined above through an interactive/dialogic communicative approach.

This is a teacher-led demonstration which focuses on the BIG circuit. The BIG circuit is a simple electrical circuit consisting of a supply and a single bulb. The defining feature of the BIG circuit is its size; it is set up to pass right around the perimeter of the classroom. The instructional activity involves the students in making predictions about what will happen when the circuit is completed. Will the bulb light immediately? Will there be a slight delay? Working from their existing ideas (of battery-as-source), students typically predict a short, but observable, delay. When the

BIG circuit is completed, the bulb is seen to light *immediately*, prompting dialogue about what is happening in the circuit and challenging the battery-as-source model.

Teaching Intervention 2: The Rope Loop

The BIG circuit teaching intervention challenges the battery-as-source model of electric circuits, but does not offer an *alternative* way of accounting for the observation of the bulb lighting immediately. This second intervention involves the introduction of the school science view (addressing the Learning Step of 'Developing, and internalizing, the school science point of view').

Specific learning goals

As outlined earlier, the learning demand analysis points to the specific learning goals for this intervention. These are for students to:

1. develop an understanding of a simple model of an electric circuit model.
2. come to recognise and understand the following specific features of the model:
   - when the circuit is completed the charges present are set in motion in all parts simultaneously
   - that the battery is the source of energy for the circuit.
   - that energy is transferred in the circuit whilst the current is conserved.
   - that the charges originate in the circuit and not in the battery.

It is important to recognise that these learning goals do not simply list the canonical school science knowledge to be taught. Having been derived via a learning demand analysis, they also reflect the key differences between school science and everyday views.

Communicative approach

The focus is on students developing an understanding of the school science model. Here the teacher needs to *lead* the talk with the class, introducing new ideas through interactive/authoritative and non-interactive/authoritative communicative approaches.

Instructional activity

The Rope Loop intervention is a teacher-led demonstration which involves using a loop of rope as an analogy for an electric circuit. The students stand in a large circle in the classroom and hold out their hands to allow the rope to pass lightly over their fingers. The teacher sets the rope loop in motion (by pulling it around) and invites one of the students to grip the rope a little more tightly. This produces a heating effect on the student's fingers. The teacher systematically develops the various links between the analogy and a simple electric circuit model (teacher/battery as source of energy; moving rope as moving charge; energy transferred in fingers/bulb).

These, then, are the first two teaching interventions of a full instructional sequence. The intention here has been to illustrate the steps involved in planning instruction starting with an analysis of the intended learning outcomes. Subsequent teaching interventions for this teaching sequence on electric circuits have been developed in a similar way and the complete sequence is referred to in the next section.

6.0 An evaluation of this approach to conceptualising and planning science teaching sequences

The approach to planning science instruction outlined in the preceding sections has been used in preparing and evaluating short teaching sequences as part of a major research project at the University of Leeds, focusing on evidence-informed approaches to teaching science (see Millar et al., in press). These teaching sequences were aimed at pupils aged 11-14 and each lasted for about 6 hours. One involved teaching introductory ideas about plant nutrition and a second provided an introduction to electrical circuits. Each of these teaching sequences was developed by a university researcher working collaboratively with three experienced science teachers in the 'Development Phase' of the project. The actual teaching schemes are available on-line at:
[http://www.education.leeds.ac.uk/devt/research/scienceed/ epse_teach_resources.htm].
Each teaching sequence was implemented by the three 'development teachers', in their own schools, as part of the normal science curriculum, and evaluated as follows.

Students' progress in relation to the specific learning goals set out for each sequence was measured by comparing responses to diagnostic questions set prior to, and immediately after, teaching. In addition, the same diagnostic questions were completed by groups of students in parallel classes (in each development teacher's school), who had followed the school's regular teaching approach, thereby providing 'baseline' information on student attainment. The schools viewed the students in these baseline groups as being of similar ability to the students in the 'case study' groups.

In order to investigate the extent to which any gains in attainment, achieved by case study groups over baseline groups, could be reproduced by teachers *not* involved in the design of the teaching, a further sample of teachers was recruited to implement the designed sequences. These *Transfer Phase* teachers had no connection with the project at all and in most cases were not known by members of the research team. The Transfer Phase teachers were provided with hard copy of the teaching scheme (including full specification of learning goals, communicative approaches and instructional activities), but were offered minimal further guidance. Test data were collected from students in these transfer classes before and after teaching with the designed sequences ('transfer case studies') using the same diagnostic questions, and from students in similar classes in the same schools following the schools' usual programmes of study ('baseline case studies').

In addition to collecting these learning data the case study classes were video-recorded in the development phase and these recordings were used to evaluate the extent to which the teacher had: i) followed the development of the scientific story as set out in the planned teaching sequences; and ii) staged the sequence of lessons, employing the range of classes of communicative approach specified in the scheme.

The key questions for the evaluation of the planned sequences were as follows. To what extent did students who followed the specially-designed biology and physics teaching sequences develop conceptual understanding consistent with the learning goals of the sequences? To what extent were the learning gains any better or worse than those of the baseline groups? How did the learning gains achieved in the development phase compare with those from the transfer phase? To what extent were the specially-designed lessons implemented as planned, both in terms of the development of the scientific content and its staging?

For the *development case studies*, students who followed the designed teaching sequences were no better or worse than students following the school's usual teaching approach (the 'baseline classes') in giving correct answers to questions requiring *factual recall*. Both groups of students, in fact, were successful in responding to such questions. However, students who followed the designed teaching were significantly better at providing *explanations* involving the correct use of scientific concepts than their peers who had followed the school's usual teaching approach. This pattern of findings was replicated in the *transfer case studies*, with slightly lower differences between case study and baseline students. A detailed evaluation of students' learning following teaching is presented in Millar et al. (in press).

The analysis of the video data from the development case study classes indicated that the teachers largely followed through the development of the scientific story as planned. In staging the story, there were, however, significant deviations from the planned movements in communicative approach. The most obvious pattern of difference was the general shortage of interactive/dialogic approaches where the teacher explores and probes the students' thinking.

7. Final comments

In this paper I have set out an approach to planning science instruction, which is based on a particular perspective of what is involved in learning science (Leach and Scott, 2003), builds on an analysis of learning demands in specific concept domains (Leach and Scott, 2002) and takes a path from learning steps to teaching interventions (Oser, 2001).

This approach was implemented by researchers and teachers working together, in planning two teaching sequences, one in biology and the other in physics (focusing on electric circuits as detailed in this account). An evaluation of the impact of the sequences in high school classrooms indicates enhanced learning gains both for classes taught by the teachers directly involved in developing the sequences and for teachers not involved at all. To this extent we have evidence to suggest that the approach to planning set out here is more effective in supporting students' learning than existing practices.

It is interesting to speculate on what might have given rise to the enhanced learning outcomes. There are various possibilities which include: careful specification of learning goals which are linked to progressive learning steps and based on a learning demand analysis, thereby taking account of students' thinking; explicit specification of the communicative approach to be taken by the teacher in each teaching intervention; instructional activities designed to directly address specific learning goals. In fact the evaluation undertaken does not allow for identification of the relative impact (on learning) of each feature. The enhanced learning gains can only be linked to the *overall* approach to planning and implementing the teaching.

The findings from the *transfer* case studies raise important questions in relation to science teacher professional development. Here we have a situation where teachers were able to take ‘teaching packages’, with a minimum of guidance, and use them with their normal classes in a way which led to enhanced learning gains. Much of the current thinking on science teacher professional development refers to the need to challenge teachers’ basic views and assumptions about teaching if their practices are to develop (see, for example, Fischler 2005) and this is likely to be a lengthy process, played out over a number of years. This perspective contrasts with the experiences of the transfer teachers. The argument here is not that the teaching packages transformed the pedagogical views of the transfer teachers, but that they were able to successfully accommodate them to their existing practices. This being the case, one might contemplate an approach to teacher professional development which is based not on a ‘top-down’ approach, starting with the ‘grand views’ of teaching and learning, but takes a ‘bottom-up’ approach, moving on from specific examples of effective practice. In the context of such a bottom-up approach, it is not difficult to imagine teachers wanting to know more about the theoretical ideas underlying these effective instructional sequences, once they have used them in the classroom.

A final and related point concerns the very positive response of the transfer teachers and other teachers (through subsequent professional development programmes) to the evidence-based teaching sequences. Combinations of instructional activities such as the BIG Circuit demonstration followed by the Rope Loop analogy, almost without exception prompt enthusiastic responses along the lines of, ‘Oh! That makes so much sense. I must try it with my classes’. In other words the teaching sequences have considerable practitioner validity. Given that the approach to planning science instruction which has been set out in this article is detailed and time consuming, it is clear that *all* science teachers do not have the time (or the specific expertise and interest) to engage in this process for all parts of their teaching. What is being suggested here is that carefully thought-through, evidence-based approaches to science instruction can be widely, and effectively, used by science teachers and can act as a starting point for further professional development activity.

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