The concept of learning demand as a tool for designing teaching sequences

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Abstract
Claims have been made in the science education research literature that one teaching sequence typically results in better student learning than another. In such studies, 'teaching sequence' typically describes the sequence of activities presented by teachers to students. The sequences tend to be designed on the basis of a detailed analysis of the scientific content to be taught, and research on students' preinstructional knowledge. Improvements in students' learning tend to be explained in terms of changes in the nature or sequence of activities. Other possible explanations for improvements in learning feature less prominently.
The paper argues for a broader view of teaching sequences. It draws upon a social constructivist view of learning to theorise what is involved in the appropriation, by individuals, of knowledge that exists in social settings. Teaching activities and the talk that surrounds them are viewed as inseparable. Teaching sequences are portrayed in terms of a flow of discourse *between teacher and students, rather than as a sequence of activities which can be talked about independently from the classroom environment in which they are conducted. Teacher talk is given a central place in accounts of teaching sequences.*
The concept of learning demand *(Leach and Scott, 1995; 1999) is developed as a tool to inform the planning of teaching, drawing upon an analysis of the scientific subject matter to be taught, research findings about students' preinstructional knowledge, and a social constructivist perspective on learning.*

The problem addressed in this paper

There is a considerable body of evidence showing that student's learning of scientific concepts can be improved as a result of research-based teaching sequences, and there are many examples in the literature where researchers suggest wholesale changes to the practice of teaching a science topic on the basis of their research. However, science education research is often viewed by policy makers and practitioners as having very little to say about teaching. How can this apparent difference in viewpoints be explained?

This paper presents a view of what constitutes a teaching sequence, accounting for some of the difficulties involved in transferring findings from research evaluations of teaching sequences more widely amongst teachers. In the first section of this paper, we consider the evidence base upon which claims about the effectiveness of teaching sequences are made. In many cases, there are overwhelming reasons why one sequence of introducing ideas makes more logical sense than another. However, we argue that researchers tend to attribute improvements in student learning to *the sequence of activities in the teaching*, giving little explicit attention to the teacher's expertise in *staging*[2] those teaching

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[2] We use the term 'staging' to describe how a teaching activity is presented and mediated by the teacher with a group of students, through language and other semiotic means.

activities for the benefit of students. The same individuals are often involved in designing the teaching sequence and teaching the lessons during research evaluations of teaching sequences. In other cases, although the teachers are not involved in designing the teaching sequence, they are given intensive coaching by researchers before implementing the teaching sequence. The 'teaching sequence' that is evaluated is therefore a sequence of activities as staged by a teacher who is not at all typical of others in the teaching force.

This raises difficulties in applying findings from research evaluations of the effectiveness of teaching sequences more widely. In particular, the extent to which other teachers would be able to use the teaching sequence and get learning gains similar to those found in research evaluations is open to question. Furthermore, few research evaluations of teaching sequences give insights into the factors that promote and constrain teachers' abilities to use the sequence of activities to promote student learning. In the second part of the paper, we present a social constructivist perspective on learning in order to theorise what is involved in teaching sequences other than a sequence of activities to be experienced by students. We develop the notion of *learning demand* as a tool for informing both the design of sequences of activities and ideas for teaching, and the staging of those sequences of activities in the classroom. The paper concludes with a brief discussion of the similarities and differences of this perspective with other research on the design and evaluation of teaching sequences.

Research to evaluate teaching sequences

There are hundreds, perhaps thousands, of studies reported in the literature which address the design and evaluation of teaching sequences. In the overwhelming majority of studies, the effectiveness of teaching is evaluated by comparing students' responses on specially designed test items before and after teaching. The use of specially designed test items allows researchers to judge the effectiveness of the teaching in meeting specifically defined learning goals. In addition, the use of classroom data allows researchers to evaluate whether students' actions when working on teaching activities matched those intended in the design of teaching (Millar et al., 1999). This approach to the evaluation of teaching allows researchers to comment upon the extent to which a sequence of teaching was successful in meeting its aims, as set out at the beginning. The following comment, taken from a study of the effectiveness of an approach to teaching dynamics, is typical of the approach taken:

> *'We should begin the process of designing instruction to meet our goals by finding out what students know and can do, instead of simply deciding what we want them to know and to be able to do. To insure (sic) that the materials we produce are well matched to students and remain responsive to their needs and abilities, research and curriculum development must be a coordinated, continuing, and iterative process.'*
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> (McDermott and Somers, 1991; p.355).

There is some evidence that, in the UK, both policy-makers and teachers want educational research to tell them something about the most effective ways of achieving stated goals (Hargreaves, D., 1996; Blunkett, D., 1999; Woodhead, C., 1998). However, pre- and post-testing does not allow for judgements about the effectiveness of designed teaching sequences compared to conventional teaching approaches. There are very few examples of research studies in science education which attempt to evaluate the effectiveness of designed teaching sequences against more conventional teaching approaches. This is hardly surprising, given the well known difficulties that are involved in making valid comparisons (Brown, 1992; Bassey, 1986). In order to design a study to compare the effectiveness of two approaches to teaching, it is necessary to establish the extent to which the populations of students who will experience the teaching approaches are comparable, and to deal with any differences. It is necessary to have assessment instruments which are not biased towards the content of one teaching approach compared to the other. Findings about the effectiveness of teaching approaches in promoting learning have to be balanced against facts about the amount of teaching time provided, and other costs.

There are a small number of studies reported in the literature which go some considerable way to dealing with these difficulties and providing evidence about the effectiveness of designed teaching sequences, compared to the usual teaching approach. Two studies will be referred to, to illustrate the kinds of claims typically made in studies comparing the effectiveness of designed teaching approaches with the usual teaching. Viennot and Rainson (1999) describe the design of a teaching sequence addressing the superposition of electric fields for French undergraduate students, and its evaluation against the usual teaching approach. They show evidence of small but consistent, year-on-year gains in some areas by students following the ‘experimental’ teaching sequence compared to the ‘control’ sequence. Brown and Clement (1991) describe the evaluation of teaching sequences on gravity and inertia to US high school students. They show gains of around 30% by students following the ‘experimental’ sequence compared to the ‘control’ sequence.

Both of the studies reported in the last paragraph provide convincing evidence that it is possible to design teaching sequences, based on research on learning, that can be more effective than the usual teaching approach in promoting student learning. In both studies, well-evidenced and plausible cases are presented as to why one teaching sequence is likely to engage with students’ reasoning better than another. In each case, the research design that was used controlled for the prior attainment of students in the ‘control’ and ‘experimental’ groups, the assessment instruments were carefully designed not to privilege one teaching sequence over another, and, in the Viennot and Rainson study, the designed teaching approach did not take any more teaching time than the usual teaching. However, for a variety of reasons it was not possible to control for one factor that has a central influence on the effectiveness of the teaching: the expertise of the teacher. The teacher has a critical role in building an atmosphere of motivation during a sequence of teaching, in asking key questions of students and responding to their comments and questions. For this reason, it would not be valid to state that one teaching sequence is *better* than another at promoting student learning, without commenting on the role of the teacher in promoting students’ motivation, and engaging with students through talk. Although some teaching sequences might well prove more intellectually satisfying than others for both teachers and students, it is certainly the case that some teachers are much more successful than others at motivating and engaging their students. One approach to controlling for the role of the teacher in evaluating teaching sequences would be to have one teacher teach both the designed teaching sequence and the usual teaching approach. However, if teachers learn things that they believe will be of benefit to their students as a result of working on the design of a teaching sequence, it is open to question whether they would not draw upon this learning when teaching in the 'usual' way. There are also ethical difficulties in asking teachers not to teach in the way that they believe to be the best for their students.

In the Viennot and Rainson study, differences between the performance of students following the 'control' and 'experimental' teaching are attributed to differences in the organisation of content within the sequences. However, the teacher in the 'experimental' teaching sequences was also closely involved in the design and evaluation of the teaching sequence (S. Rainson). The 'control' classes were taught by teachers who were not involved in the research study (Viennot, 2000, personal communication). It is therefore possible that the noted gains in learning are due as much to improvements in the effectiveness of the teacher in engaging with students' thinking, as to changes to the teaching sequence.

The same issue is apparent in the Brown and Clement study. Little information is given about the teachers who taught the lessons, though the text of the paper seems to suggest that the same group of teachers taught both groups of lessons. However, the 'control' lessons were taught at an early stage in the research, before the teachers were fully immersed in the research process (Brown, 2000, personal communication). It is therefore unlikely that the teachers' teaching of the 'control' classes would have been greatly influenced by their experience of being involved in the research project. 2 iterations of 'experimental' teaching sequences were conducted, and significant improvements in student learning were only noted on the second iteration. Brown and Clement attribute this to three factors:

1) *'As our team gained a more detailed understanding of the 'conceptual territory' in these areas, it allowed us to design more 'conceptually focused' examples which dealt with specific difficulties;*
2) *Each unit was split into two sections separated by weeks allowing for 'revisiting' of topics;*
3) *Many more occasions where students give oral or written explanations were included.'*

(p.383)

It is noticeable that the researchers do not make reference to the influence of the team's development of 'a more detailed understanding of the "conceptual territory" ' upon the teachers' expertise at posing questions that engage with students' thinking, and responding to students' talk. It seems to us that changes in the ways in which the teachers engage with students in the classroom as a result of their knowledge about the 'conceptual territory' go hand in hand with changes in the sequence of activities itself in explaining the gains in learning noted in the study.

The implications of a social constructivist perspective on learning for designing and evaluating teaching sequences

In this section we draw upon a social constructivist perspective on learning, which has been presented in detail elsewhere (Leach and Scott, 1995; 1999), to inform the development of a broader view of ‘teaching sequences’ than that normally found in the literature. We begin by setting out some fundamental aspects of this perspective, which draws heavily on Vygotskian and neo-Vygotskian perspectives (Vygotsky 1987; Bakhtin 1981; Wertsch 1985b; Scott, 1998).

A social constructivist perspective on learning: fundamental assumptions

Central to Vygotsky’s perspective on development and learning is 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) provide the means for ideas to be talked through and communicated on the social or intermental plane and following the process of internalisation, language provides a tool for individual thinking. In this way talking and thinking are considered to be continuous, as language first encountered on the social plane provides the tools for individual thought.

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 unconsciously through normal day-to-day interactions whilst scientific concepts are those formal concepts which originate in particular disciplines (such as physics or geography or psychology) and which can only be learned through instruction.

We take it as axiomatic that social processes are also fundamental to the generation and validation of scientific knowledge (taken here as being the natural sciences). This should not be interpreted as an endorsement of a relativist ontology (Matthews, 1997; Nola, 1997). Rather, we use the phrase to make two points: (1) communities of scientists (and science teachers) make choices about the scientific knowledge that it is appropriate to use in different situations; and (2) the knowledge used by scientists (and science teachers) is underdetermined by data - concepts such as ‘gene’, ‘force’ and ‘electron’ are used to model data for specific purposes. Scientific knowledge is not therefore to be found in experiments or data, and learners will not stumble upon the formalisms, theories and practices that form the content of science curricula without being introduced to them through teaching.

Bakhtin (1986) refers to the different *social languages* used by specific communities of people for particular purposes. Thus, for example, the language used by solid state physicists in talking about the structure of ceramics forms part of one social language, and the language used by potters to talk about the moulding properties of ceramics is part of another. Wertsch (1991, pp.93-118) makes use of the concepts of social language and speech genre in suggesting that the various forms of mediational means be viewed not as some kind of single undifferentiated whole, but rather in terms of the diverse items that make up a *tool kit*. Following this perspective, the different social languages and speech genres which are rehearsed on the intermental plane of the classroom offer the means for developing a range of distinctive modes of personal thought: a whole kit of mediational tools. Thus it is quite possible that the physicist with an interest in pottery (and, indeed the potter with an interest in physics) is able to use both the language of solid state physics and that of the pottery craft in describing, explaining and thinking about various properties of ceramics.

There is compelling evidence that the process of learning to describe, think about and explain natural phenomena scientifically can be very difficult. There now exists a wealth of information about the ways in which science students tend to talk and think about the physical world, and how students tend to respond when scientific ideas are presented to them during teaching (Pfundt and Duit, 1994). Much of this is essentially descriptive, saying what students did when presented with particular diagnostic questions, interview tasks or classroom activities. In other cases, researchers have gone some way in characterising differences between the ways in which students typically think about (or talk about) the physical world, and scientific accounts of the world. For example, there is a good deal of evidence that students' descriptions of natural phenomena and events across the scientific disciplines of physics, chemistry and biology differ in both their ontology (Chi 1992; Chi et al., 1994; Vosniadou, 1994; Leach et al., 1996) and epistemology (Vosniadou, 1994; Driver et al., 1996; Leach et al., 1996) from the scientific concepts that describe the same phenomena. In the next section of the paper, information about the ways in which science learners think and talk about the natural world will be used in conjunction with perspectives on thought and language to inform the design and evaluation of teaching sequences.

Implications of this social constructivist perspective on learning for the design and evaluation of teaching sequences

Drawing on the ideas set out above, science teaching can be conceptualised in terms of introducing the learner to one form of the social language of science and it is clear that the teacher has a key role to play in mediating that existing public knowledge. Bruner (1985) draws attention to this central role of the teacher in stating that:

> *Vygotsky's project [is] to find the manner in which aspirant members of a culture learn from their tutors, the vicars of their culture, how to understand the world. That world is a symbolic world in the sense that it consists of conceptually organised, rule-bound belief systems about what exists, about how to get to goals, about what is to be valued. There is no way, none, in which a human being could master that world without the aid and assistance of others for, in fact, that world is others.*
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> (Bruner, 1985, p.32)

So, how do students in school learn scientific knowledge from their teacher? The first key feature of the instructional process, from this social constructivist perspective, is the way in which the teacher develops or 'stages' the 'scientific story' on the social plane of the classroom. Specific *activities* are included in the teaching sequence on the basis of how they can be used to make the scientific story available to students. The activities (be they teacher demonstrations, student experiments or student reading exercises) 'carry no message' in themselves. Rather, meanings have to be introduced, rehearsed and checked on the social plane in such a way that students and teachers in the classroom develop shared 'common knowledge' (Edwards and Mercer, 1987) of the phenomena and events under discussion. This staging of the scientific story takes place over a period of time The fundamental issue in planning a teaching sequence is how each activity can be used to contribute to the development of the conceptual and epistemological themes (Scott, 1998) which constitute that scientific story.

In considering this development of the scientific story or 'teaching narrative' (Scott. 1998), we have found it useful to draw on the distinction made between the 'authoritative' and 'dialogic' functions of text (see Wertsch, 1991; Mortimer, 1998; Scott, 1997) in analysing and thinking about classroom discourse. The principle function of authoritative discourse is to introduce ideas onto the social plane, whereas dialogic discourse involves the exploration of meaning on the social plane with a view to building shared understandings and allowing learners to appropriate meanings. In the classroom, authoritative discourse might see the teacher presenting ideas in a way which offers students no invitation to discussion. Dialogic discourse might see the teacher asking for, and discussing, student opinions; it might involve students discussing ideas with each other. It seems reasonable to suggest that learning in the classroom will be enhanced through achieving some kind of *balance* between presenting information (focussing on the authoritative function) and allowing opportunities for exploration of ideas (focussing on the dialogic function). In this sense there needs to be an appropriate *rhythm* (see Mortimer 1988; Scott, 1997) to the discourse.

The ideas discussed in the preceding paragraphs focus on the talk of the social plane of the classroom. There is clearly a difference between making the scientific story *available* on the social plane and having individual students make personal sense of, and, take on (or appropriate), that story. Vygotsky refers to this personal sense-making step as involving the process of *internalisation.* A second key feature of the instructional process therefore concerns the ways in which the teacher can act to support students in making sense of and internalising the scientific story. Here Vygotsky refers to the role of the teacher as being one of supporting student progress in the Zone of Proximal Development (ZPD), from assisted to unassisted competence. How might such teacher assistance appear in the classroom?

The first point to be made here is that the teacher's interventions to support internalisation of the scientific story by students are made *throughout* the teaching sequence; it is not a case of making the scientific story available and *then* helping the students to make sense of it. In this respect we consider that the continuous *monitoring* of students' understandings and *responding* to those understandings, in terms of how they relate to the intended scientific point of view, must be central to the teacher's role. Of course, these processes of monitoring and responding are made more difficult by the fact that the teacher is not working with one student at a time but with a whole class of students. Nevertheless, we would expect the teaching sequence to include opportunities for monitoring student understandings (through, for example: whole class questioning and discussion; small group activities; individual writing activities...). We would also expect the teacher to respond to developing student understandings (by, for example, sharing particular points in class, challenging particular points in class, offering comments on student written exercises, discussing issues with individual students where time allows). As the teacher is engaged in these linked processes of monitoring and responding, they are probing and working on the 'gap' between students' existing understandings and the intended learning goal; they are working in the zone of proximal development.

A third and final feature of a teaching sequence informed by a social constructivist perspective involves providing opportunities for students to 'try out' and practice the new ideas from the scientific social language for themselves, to make the new ideas 'their own'. This step of applying ideas might first be carried out by students with the support and guidance of the teacher. As the students gain in competence and confidence, the teacher gradually hands over (Bruner 1983) responsibility to them, moving towards student capability in unassisted performance.

The conceptualisation of 'teaching sequence' which is presented here is rather different from that which is commonly found in the literature. Our reading of the literature addressing the design of teaching sequences (including the studies referred to in the previous section) suggests that a lot of attention is given to identifying teaching activities, and relating them to students' pre-instructional knowledge and to the scientific knowledge to be taught. The teaching sequence tends to be conceptualised in terms of teaching/learning activities, with no reference to the talk which surround them. Our view is different. It seems to us that central to any teaching sequence is the way in which the teacher works with their students to 'talk into existence' (Ogborn et al, 1996) the scientific story. From our point of view, the activities which are often used in science lessons (experiments, demonstrations etc.) are important, but only insofar as they can act as points of reference in the development of the scientific story. We believe that those instructional design studies which attribute increased student gains to particular sequences of activities are missing the point, the point being that those activities are mediated or 'brought into action' by the teacher and the way that the teacher achieves this is fundamental to the teaching process and of overwhelming importance in influencing student learning.

The concept of learning demand as a tool to inform the design and evaluation of teaching sequences

Although there are many examples of how teaching sequences might be designed and evaluated in the science education literature, relatively few papers are explicit about how the available information about learners' preinstructional ideas and the science to be taught are drawn upon in planning the teaching sequence. Notable exceptions include work in the (continental) European didactic tradition (Tochon, 1999), which can be exemplified in science education by studies such as those of Tiberghien (1996) and Lijnse (1995). In this section of the paper we develop the notion of *learning demand* (Leach and Scott, 1995; 1999), which we relate to Bakhtin's notion of 'social languages', as a tool for theorising the process of designing and evaluating teaching sequences, and compare and contrast learning demand with those theoretical tools used in the (continental) European didactic tradition.

The concept of learning demand

The point was made earlier 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. It is the language which provides the means for communicating with others, it provides a way of talking and thinking about all that surrounds 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. 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 is different from both.] 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. From a social constructivist point of view, it is evident 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).

A further important distinction can be made between what might be referred to as ‘scientific’ social languages and a ‘school science’ social language. It is clear that there are differences between ‘real’ science and ‘school’ science. School science has its own history of development and is subject to social and political pressures which are quite different from that of real science. The science which is taught in schools focuses on particular concepts and ways of thinking and can therefore usefully be thought of as constituting a social language in itself.

The concept of ‘learning demand’ offers a way of appraising the *differences* between the social language of school science and the social language which the learner brings to the classroom. The purpose of identifying learning demands is to bring into sharper focus the intellectual challenges facing the learner as they address a particular aspect of school science; teaching can then be designed to focus on those learning demands. Let us now consider, in a little more detail, various aspects of the concept of learning demand.

The first point to be made is that a ‘learning demand’ is specific to the particular content being taught. Thus, if a sequence of lessons is to address the scientific concept of ‘energy’, then a comparison between everyday and scientific notions of energy will provides insights to the nature of the learning demand (for example, in everyday discourse energy is something which gets ‘used up’; in science, energy is ‘conserved’).

A second point is that a learning demand can be identified for a *group* of learners (as well as the individuals who constitute that group). 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 apparatus’ of individuals. In this sense the concept of learning demand is *epistemological* rather than *psychological* in nature (Leach and Scott, 1999).

How might the nature of the learning demand for a specific conceptual area of science be described? We have identified three ways in which differences might arise. 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 in the *conceptual tools* used. In relation to the scientific concept of photosynthesis, students commonly import everyday notions of ‘food’ which contrast with the scientific story of food synthesis. In other cases, as we shall see, students inappropriately draw upon generalised rules of reasoning such as ‘more of (a) means more of (b)’.

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 social language of many learners. Thus, there is evidence that many lower secondary school students recognise the logical implications of specific pieces of evidence in relation to different models of simple series electrical circuits, but resolve logical inconsistencies by selecting different models to explain the behaviour of different circuits (Leach, 1999). They do not draw upon the epistemological principle of *consistency* that is an important feature of school science. Their social language does not appear to recognise that scientific models and theories ideally explain as broad a range of phenomena as possible.

Further aspects of learning demand may follow from differences in the *ontology* on which the conceptual tools that are used are based. 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 social 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 basic commitments about the nature of matter - taking gases to be substantive.

Drawing on the concept of learning demand and social constructivist perspectives to inform the design of teaching sequences

Drawing upon the ideas set out in the previous sections, the following scheme offers a generalised approach to guide the planning of science teaching:

1. identify the school science knowledge to be taught;
2. consider how this area of science is conceptualised in the social language of students;
3. appraise the nature of any differences between 1 and 2 (the learning demand);
4. develop a teaching sequence, which includes a sequence of activities plus information about the staging of those activities through talk, to address each aspect of that learning demand.

Step 1: The school science knowledge to be taught

Identifying appropriate learning goals for a teaching sequence inevitably involves making decisions. However, teaching sequences are often reported in the literature with no details about how scientific content was identified as appropriate for teaching. In the first instance, it is necessary to identify which aspect of the scientific social language is to be focussed upon. Thus, students might be introduced to the idea that heat is equivalent to work (drawing on the social language of engineers), or the relationships of calorimitery (drawing on the social language of thermodynamicists) (Tiberghien, 1996). Alternatively, the focus might be on the perspectives of groups such as environmental activists (Larochelle and Désautels, in press).

Steps 2 and 3: The social language of learners and its relationship to school science

The nature of the social knowledge that learners bring to lessons and the relationship of that knowledge to school science vary according to the scientific content area of the teaching, and the age and experience of the learners.

In some areas there are striking differences between 'everyday' social language and the 'school science' social language introduced through teaching (Driver et al., 1994; Leach and Scott, 1999). For example, learners commonly consider that heavy objects require a 'force' to keep them moving, prior to encountering Newtonian mechanics in school science lessons (which is based on the premise that no such force is required). For the learner, coming to the perspective of Newtonian mechanics after years of everyday talk (which acts to shape day-to-day experience) can be an intellectually disorienting experience. Familiar phenomena (objects moving), are talked about in ways which seem to run counter to common sense, furthermore the vocabulary used ('force', 'motion', 'speed', 'acceleration') may be the same in 'everyday' and 'school science' social languages, but the meanings that constitute the words are quite different.

There are other situations where there may be differences between school science and everyday views, but the relationship is less direct. Consider, for example, secondary school students learning about genetics. Students are likely to have many everyday ideas to explain why offspring look similar to, or different from, other family members. However, although secondary school biology addresses heredity, its main focus is upon the structure, coding, transfer, and interpretation of genetic information. These aspects of the social language of school science do not have corresponding points of reference in everyday social language.

Nevertheless, in the case of genetics learning, there is some evidence that students develop ways of interpreting content, introduced through school science, in terms of the fundamental assumptions developed through everyday talk. For example, the idea that 'everyone is unique' is common in everyday social language. When students are taught that the *genetic code* is how information is coded through the chemical structure of DNA, many students interpret the genetic code as providing a 'blueprint' for each individual, similar to an unique 'bar code' (Lewis et al., 2000). In such cases, it appears that many learners develop a perspective which incorporates features of everyday social language and the target school science, but that is different from both.

In other cases, students may bring more general forms of everyday reasoning to school science contexts. This can be illustrated with the phenomenon of hotness/coldness. Prior to teaching, students are surrounded by perceptual experiences that 'hotness' and 'coldness' are different, and that things get hotter as they are heated (and cooler as they are cooled). Furthermore, there is much talk where parents tell children that the nearer you get to hot fires, the hotter you get, and so on. During school science teaching, however, students encounter phenomena where more heating does not result in more 'hotness' (e.g. when heating a substance around the point of phase transition). In such cases, many students draw upon reasoning patterns (or everyday patterns of talk) such as 'more of (a) leads to more of (b)', to offer explanations (Andersson, 1986; Stavy and Berkovitz, 1980). In such cases, the knowledge that students draw upon involves more general patterns of reasoning about relationships between quantities.

Of course there are many contexts of school science learning where there is considerable overlap between everyday and school science views. For example, basic notions of the human skeleton are unlikely to differ much between everyday and school science views, although school science will offer extra information regarding structure and function and a new terminology. We would suggest that it is in these areas of overlap between social languages where teachers regard topics for study as being ‘straightforward’ and learners think the topic is just ‘commonsense’.

Step 4: Developing a teaching sequence

We believe that the concept of Learning Demand can inform the *selection and sequencing* of activities in a teaching sequence, planning the *kind of talk* (along the authoritative-dialogic dimension) that is appropriate at different points in the teaching sequence, and decisions about the *content of the teacher talk* (referring to both conceptual and epistemological issues) during particular teaching activities.

In thinking about the overall ‘shape’ of a teaching sequence, we see it as involving the gradual and progressive development of the conceptual and epistemological themes identified through the learning demand analysis.

We shall now illustrate this approach to designing teaching sequences by focusing on a particular example relating to introductory work on simple electrical circuits.

Designing a teaching sequence: An introduction to explaining the working of simple electrical circuits

In the UK, the study of simple electric circuits is first addressed with students in the 11-14 age range.

Step 1: School science knowledge to be taught

In the context of the National Curriculum for Science in England and Wales (DfEE, 1999) the school science knowledge to be taught is likely to be limited to developing a model of energy transfer via an electric current, where current is conserved and energy is transferred in resistive parts of the circuit (this model is developed in subsequent phases of the National Curriculum by introducing the concept of voltage). According to the National Curriculum, the model involves conceptualising:

- current as a flow of charge
- current as the means of energy transfer
- current as being conserved
- the supply of energy as originating in the electrical cell
- energy being transferred in resistive elements of the circuit.

Step 2: Students’ everyday views of electricity and electrical circuits

With students of this age, it is likely that they will arrive at the lessons with a variety of everyday ideas about electricity:

- ‘batteries run out’;
- ‘electricity makes things work’;
- ‘current, electricity, volts, power are the same kind of thing’;
- ‘electricity/electric current flows’.

They use electrical appliances on a daily basis and take for granted that these things: ‘must be switched on’; ‘cost money to work’; ‘can be dangerous in giving electric shocks’.

As teaching in this area proceeds it is quite common for students to develop ideas such as:

- ‘current gets used up’
- ‘the battery provides a fixed current’

and to confuse the concepts of charge, current, energy, electricity.

In relation to broader epistemological issues, it is likely that the students:

- have little experience of using a scientific model which involves 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).
- have little appreciation of the fact that scientific models can be applied generally to a wide range of contexts.

Step 3: Learning demand analysis

Aspects of school science to be addressed	*Students’ typical everyday views:*
A simple model of an electric circuit which involves: • current as a flow of charge • current as the means of energy transfer • current as being conserved • the supply of energy as originating in the electrical cell • energy being transferred in resistive elements of the circuit.	*Prior to teaching:* • ‘batteries run out’; ‘batteries go flat’ • ‘electricity makes things work’; • ‘current, electricity, volts, power are the same kind of thing’; • ‘electricity/electric current flows’. *During/after teaching:* • ‘current gets used up’ • ‘current, charge, electricity, voltage are confused’ • ‘battery provides a fixed/steady current’. • have little experience of using a scientific model which involves moving between the microsopic world of the model (based on the abstract concepts of energy, charge and current) and the macrosopic world of observations and measurements. • have little appreciation of the fact that scientific models can be applied generally to a wide range of contexts

By comparing the different views set out above, looking for commonalities and differences, the learning demand is seen to involve the student in coming to:

- develop abstract scientific concepts of charge, current, energy in the context of simple electric circuits.
- understand that the current carries energy in the electric circuit
- understand that it is the energy which is ‘used up’ (transferred) and not the current.

- understand that the theoretical model based on concepts of charge, current, energy can be used to predict and explain the behaviour of simple circuits.
- appreciate that scientific models can be applied generally to a wide range of contexts.

The first three elements of the Learning Demand involve conceptual issues whilst the final two elements pertain to epistemological matters.

The learning demand identified for a particular topic often highlight aspects of the subject matter as centrally important from the point of view of teaching, that would not be identified as important from an analysis of the subject matter alone. In the case of electric circuits, for example, an analysis of the subject matter would take for granted a commitment to generalisability and consistency of explanation. By contrast, however, information about the social language of students makes it apparent that this aspect of the social language of school science can not necessarily be taken for granted with lower secondary school students. Similar issues are also raised in the studies of Viennot and Rainson (1999) and Brown and Clement (1991).

Step 4: Planning the teaching sequence

We now turn our attention to planning a teaching sequence to address the Learning Demand set out in the previous section. The first step in this process is to develop *Teaching Goals* which make explicit the ways in which students’ ideas and understandings are to be worked on through the intervention and guidance of the teacher. The teaching goals are grouped according to whether they have a conceptual or an epistemological focus:

Conceptual teaching goals:

To *build on* the idea that:

- batteries make things work
- electricity/current flows

To *introduce, and support the development of*, the idea that:

- an electric current consists of a flow of charge.
- the electric current has the job of transferring energy

To *draw attention to, and to emphasise,* the idea that:

- the electric current does not get used up
- it is the energy which is transferred in resistances to make things work.

Progressively to *differentiate between*:

- the theoretical concepts of charge, current, energy.

Epistemological teaching goals

To *introduce, and support the development of*, the idea that:

- the theoretical model based on concepts of charge, current, energy can be used to predict and explain the behaviour of simple circuits.
- scientific models can be applied generally to a wide range of contexts.

The overall shape of the sequence

In thinking about the overall shape of this teaching sequence, a fundamental issue to be addressed concerns the way in which the scientific model is introduced. It seems to us that there are two main possibilities. Firstly, it might be decided to take an 'inductive approach' to introducing the scientific model; such an approach would involve making observations and measurements of simple circuits and then working with the students to develop a theoretical model consistent with those data. An alternative approach is for the teacher to introduce a simple model (of charge/current carrying energy around the circuit) and checking out the 'fit' of this model with observations and measurements. Either teaching route is possible, but we favour the second one. Here the teacher can help students to develop an understanding of the concepts charge/current/energy as the model is introduced and these understandings can then be further developed through working empirically with the model. In the first approach it seems that the students are required to make measurements of electric current before they have an understanding of what current is.

Introducing the science model

What might be involved in, 'introducing a simple model (of charge/current carrying energy around the circuit) and checking out the 'fit' of this model with observations and measurements?'. It is not appropriate, in the context of this paper, to offer great detail about the development of the teaching sequence, but hopefully the following will provide some insights to the process involved.

The teaching approach taken places responsibility on the teacher to introduce and develop the science model. This 'model-building' phase engages the students in coming to understand a theoretical and abstract representation and it is likely that the teaching would be based upon the use of a real-world analogy (possibly, for example, in getting the students to act as a flow of energy-carrying charges, moving round a circuit in the classroom). A starting point for developing the model would be that in a simple battery-bulb circuit, the battery provides energy and that *something* must be carrying the energy from battery to bulb. As specified in the teaching goals, the crucial point is to emphasise that energy is transferred in the resistance of the bulb and current is conserved.

The whole focus of this phase of the teaching is on 'talking into existence' (Ogborn et al, 1996) the model and its component concepts. The authoritative voice of the teacher will be heard as new ideas are introduced and developed on the social plane of the classroom. At the same time there must be opportunities for the teacher to check students' developing understandings, through dialogic exchanges with the whole class, small groups, individuals and also through short written tasks. There must also be opportunities for the students themselves to begin to try out these new ideas, through discussion both with the teacher and with other students. The teaching sequence thus consists not only of the specific analogy used to introduce the circuit model, but crucially of the talk and various forms of interaction through which the analogy is staged. These are planned in advance and form an *integral* part of the teaching sequence.

An additional and important part of the 'model-building phase' is for the teacher to introduce and develop ideas about the nature and purposes of scientific models in general and of the circuit model in particular (thereby starting to develop the *epistemological line* of the teaching sequence). These ideas will serve to provide an organisational framework for the teaching (developing a model, relating it to empirical data, applying the model in a range of contexts).

Working with the model

Following the model-building phase, students are given the opportunity to work with it in a number of familiar and new contexts. We see working with the model as being crucial to enabling the students to make the model their own. Sutton (1996) makes the point that 'the teacher's personal voice is important but learners must also have some freedom of re-expression' (p. 149). Here the teacher plans opportunities for students to talk through their developing understandings both with the teacher and with each other. The teacher is thereby able to monitor student progress and to intervene as necessary to scaffold (Wood et al, 1976) the learning of individuals and small groups. This phase of the teaching is planned around a series of contexts progressively differentiated in terms of the demands made in applying the model.

The aim is for the teacher to gradually 'handover' (Bruner, 1983) responsibility for applying the model to the students as they work through a number of different contexts. With this approach, the scaffolding function of the teacher is achieved both through dialogic interactions with the students anfd through careful selection of of learning activities (Scott, 1998). By the end point of the teaching sequence it is likely that different students will have worked at different speeds and therefore have covered different ranges of contexts.

We have seen how considerations of learning demand influence the choice of task or problem in a teaching sequence, the use of different kinds of talk to introduce ideas on the social plane, to build shared meanings on the social plane or to facilitate internalisation by learners. We find it useful to draw upon the Vygotskian notion of learning as assisted performance in the zone of proximal development (the ZPD; Vygotsky, 1978) to illustrate the various uses of learning demand. For our purposes, we define the ZPD as the distance between a learner's independent performance on a given task or problem, and that learner's performance with the assistance of a more able teacher or peer. Figure 1 illustrates how learning demand is used to influence the selection of activities in a teaching sequence, and to inform the kind of assistance given to learners by teachers through dialogic talk:

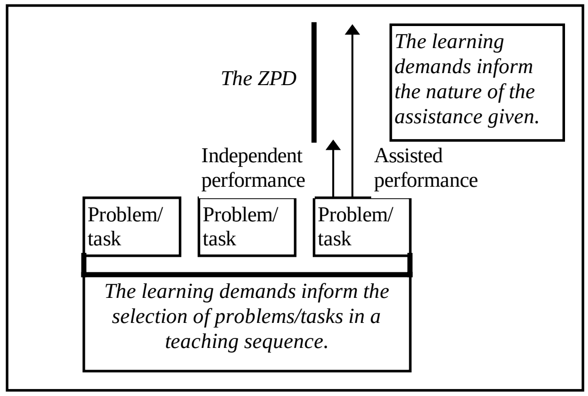

Figure 1: The use of learning demand in selecting teaching activities and informing teacher talk in the Zone of Proximal Development

How does the notion of learning demand compare to other tools identified in the literature for planning teaching?

As indicated earlier, there are several examples in the literature where conceptual tools other than learning demand have been used in the design and evaluation of teaching sequences. Most of these are from the (continental) European didactic tradition (Sjøberg, 1996; Lijnse, 2000; Tochon, 2000). We make no attempt to provide a comprehensive review of such studies in this paper, but rather examine one programme of work in order to illustrate similarities and differences in the approaches used. We have chosen the work of Andrée Tiberghien (1996; 2000) and her associates on the design and evaluation of teaching sequences for upper secondary school physics students. This body of work was chosen as being amongst the best in the field, and because it includes explicit details about the rationale for the design of teaching sequences.

Tiberghien and associates' work on the design of teaching sequences

Tiberghien (1996; 2000) describes work carried out by her and her associates to design and evaluate teaching sequences for French upper secondary physics students, addressing energy and sound. The concept of 'didactical transposition' (*transposition didactique*, Chevellard, 1991) explains how the knowledge to be taught in educational settings is identified with reference to the use of knowledge in various scientific communities. Tiberghien's description of this process is similar to our own understanding. Once the knowledge to be taught has been identified, it has to be 'manipulated' (Tiberghien, 2000; p.xx) in order to break it down and integrate it into teaching activities. A system of classifying knowledge into two worlds, the world of objects and events and the world of theories and models, is presented (Tiberghien, 1996; p.xx). The process of classifying knowledge as belonging to each world, is described as follows:

> *'The world of objects and events refers to all observable aspects of the material world, whereas on the other hand, the world of theories and models refers to theoretical aspects and elements of the constructed model of the material situations, in terms of various principles, parameters or quantities.'*
>
> (Tiberghien, 2000; p.xx)

The process of identifying learning demands shares some features in common with this classification. For example, we saw earlier that the social language of learners prior to teaching is likely to include the word ‘particle’, though the word ‘particle’ as used in the social language of school science has a different and more formal meaning. However, when identifying learning demands the central emphasis is on comparing the social languages of school science and of learners prior to teaching, rather than whether entities are in the world of objects and events, or theories and models. In some cases, the social language of learners prior to teaching and the social language of school science will both include similar entities from the world of theories and models. In such cases, a learning demand would not be identified.

Drawing upon Brousseau and Balacheff, Tiberghien (2000, p.ss) uses the concepts of ‘devolution’ and ‘didactical contract’ to describe the process of transferring responsibility for learning from teacher to students during teaching sequences:

> *‘The teacher must therefore arrange not the communication of knowledge, but the devolution of a good problem. If the devolution takes place, the students enter into the game and if they win learning occurs. But what if a student refuses or avoids the problem, or doesn't solve it? The teacher then has the social obligation to help her [...]. Then a relationship is formed which determines -explicitly to some extent, but mainly implicitly- what each partner, the teacher and the student, will have the responsibility for managing and, in some way or other, be responsible to the other person for. This system of reciprocal obligation resembles a contract.’*
>
> (Balacheff et al, 1997, cited in Tiberghien, 2000; p.ss)

When using learning demands to inform the design of teaching sequences, it is necessary to identify the parts of the teaching sequence where ideas are introduced to learners on the social plane through authoritative discourse, and the parts of teaching where dialogic discourse is used to support internalisation by students. However, the notion of authoritative and dialogic discourse shows how teachers can support internalisation by students, an issue not addressed in Tiberghien’s account of didactical contract and devolution.

The sequences of teaching activities designed by Tiberghien and her associates on the basis of a body of theory in didactics, could equally have been designed using the notion of learning demand. However, there are key differences in emphasis between how those teaching activities were ‘staged’ (*mise-en-scène*, Tiberghien, 1996; p.102) on the basis of theory in didactics, and how they would be ‘staged’ on the basis of the identification of learning demands. This can be illustrated by the example of students working to ‘construct a symbolic representation, in terms of the model [of energy], of the experimental setting [a battery operating a motor to lift an object].’ (Tiberghien, 2000; p.109). The teaching was designed to require students to work on this problem in pairs, without any intervention from the teacher, with the intention of supporting ‘devolution’. However, in our view the learning demand to be addressed in this case involves enabling students to use a new social language (involving modelling devices in terms of their role in energy transformation). In order to do this, the teacher’s role would involve promoting dialogic discourse, with the dual functions of supporting internalisation on the part of students, and allowing the teacher to listen to student talk and assess their learning. Dialogic discourse between students might be stimulated by the teacher asking questions that support development within the ZPD. Dialogic discourse involving the whole class might involve the teacher in asking questions and responding to student talk.

Accounts of teaching sequences which describe activities, but make no mention of the talk that surrounds those activities, do not adequately describe the teaching actually experienced by students.

The evaluation of teaching sequences

We now turn our attention to the evaluation of teaching sequences. The usual approach to evaluating teaching sequences is to carry out some kind of assessment of student learning against the learning objectives addressed by the teaching. This approach to evaluation is clearly important, as the primary aim of teaching sequences is to promote student learning. However, this approach to evaluation can say nothing about the *cause* of any learning gains that are observed, because no data are collected about how the teaching was conducted. The extent to which learning gains are due to the sequence of activities that constitute the teaching sequence, or the teacher's ability to motivate the students and use authoritative and dialogic talk to assist their performance, remains open to question. If researchers only have data about learning gains and the sequence of teaching activities used, in the absence of information about how those activities were staged, their communication of the teaching sequence to other teachers will be very limited. It would certainly come as no surprise if different teachers achieved very different outcomes in terms of student learning with comparable groups of students, by following the same sequence of activities without any attempt to stage those activities in the same way.

In terms of a social constructivist perspective on learning, the evaluation of teaching sequences involves measurement of student learning outcomes together with insights about how sequences of activities were staged in the classroom. Teaching would be evaluated to determine the extent to which classroom discourse had indeed followed the pattern designed in the teaching sequence. For example, classroom data would be collected to evaluate which learning demands were addressed through authoritative discourse by the teacher, how dialogic discourse was promoted by the teacher to support students in their early attempts to use the social language of school science, and how the social languages used by students were responded to by the teacher as she/he worked to assist students' performance.

In order for research on the development and evaluation of teaching sequences to inform the practice of a broad range of science teachers, it is necessary to be clear which aspects of teaching sequences were instrumental in promoting students' learning and therefore worth communicating to teachers. At the beginning of this paper we indicated that the teachers of the 'experimental' teaching sequences reported in the research literature are not typical of others in the teaching force due to their involvement in the design and implementation of the research. However, this should not be taken as indicating a belief on our part that those teachers are in some way *special* or *superior* to other teachers. Rather, we believe that those teachers have developed particular insights into the teaching of a topic that serve them well in their teaching. The challenge for evaluations of teaching sequences is to identify the aspects of the teaching activities and their staging by the teacher that were instrumental in promoting students' learning, and consider how these can be passed on to other teachers who were not involved in the research process.

In order to provide policy-makers and practitioners with the evidence they desire about the most effective ways of achieving stated goals, it is necessary for policy-makers, researchers and practitioners to build more sophisticated, shared understandings about the nature of educational phenomena. It is therefore important for those with an interest in research on teaching and learning science - whether teachers, policy-makers or professional researchers - to be realistic in their aspirations for research. If the expectation is that research to evaluate teaching sequences will show an unique, 'best' way of teaching a topic that is applicable with all classes and all teachers, then the research will always be judged to have failed. By contrast, if the aim of research on teaching and learning is viewed more broadly as clarifying the learning goals which teachers and curriculum developers have for students, developing teaching sequences to address those goals(which involve sequences of activities together with information about the staging of those activities), and obtaining feedback to determine whether the pedagogical strategies adopted have been successful (Driver, 1997), then we think that it is possible to identify a legitimate research agenda on the design and evaluation of teaching sequences.

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