Evidence-based Practice in Science Education (EPSE) Research Network

Evaluating an evidence-based approach to designing and implementing a teaching sequence about plant nutrition

Andy Hind, Jenny Lewis, John Leach, Phil Scott.


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Abstract
Although there is now a significant database of research evidence about students’ learning of biological concepts, there is general scepticism as to whether this research has had any impact on the practice of teachers. A likely reason for the low impact of research is that little is known about what is involved for teachers in drawing upon research findings about learning to improve practice. In this paper we present findings from a study that is investigating the process of transforming research evidence into improved classroom practice. In particular the study is looking at what is involved for teachers in implementing teaching sequences, the design of which is informed by research evidence about teaching and learning. In this paper we use the context of plant nutrition to evaluate a model for using research findings about teaching and learning. The application of this model has generated a new teaching sequence about plant nutrition. Data on the learning outcomes of this study show gains in pupils’ understanding of plant nutrition concepts resulting from the implementation of this teaching sequence. We also present data about the extent to which the nature of classroom interactions reflects the teaching approaches as designed in the teaching sequence and the extent of similarities and differences between three case study teachers. The findings of this paper have implications for improving the impact of research evidence on practice, and offer some insights into what is involved for teachers in implementing evidence-based teaching sequences.

Introduction
If we are to be able to offer generalisable tools for improving the impact of research evidence in classrooms we need to have a better understanding of how the classroom context influences the way research based interventions are implemented. Much of the current debate in the UK about evidence based practice in education centres around philosophical reactions to medical or engineering-based models of evidence-based practice (Hargreaves, 1999; Elliot, 2001). Rather than engaging in the debate this paper seeks to present a model of evidence-based practice that is able to demonstrate resultant gains in pupils' understanding of a biology topic and explores some of the issues that influence the way teachers engage with this model.

Theoretical and methodological underpinnings
The term evidence-based practice is borrowed largely from the field of medicine and implies a model of evidence-based practice which we do not look to transfer to education. Not only would we argue that education research doesn’t offer the possibility of ‘evidence’ in the same sense as would be recognised in medical science, but also that an intervention in education is not as clearly defined as a medical intervention might be. Whilst this study involves comparing a planned intervention with existing practice we recognise that the intervention as planned and the intervention as enacted by individual teachers may be considerably different. Hence, the model we adopt is perhaps better described as evidence-informed practice. We do
not claim that educational research offers us knowledge of the best way to teach in the way it might determine the best treatment in medicine, but that research evidence can provide insights into the challenge for learners in particular concepts. The teaching sequences developed in this study also draw upon insights from theoretical perspectives on teaching and learning that cannot be described as evidence but nonetheless offer the possibility of improving the effectiveness of teaching.

An overview of the model of ‘evidence-based practice’ that we adopted in the design of the teaching sequence is given in figure 1. This approach stems from the work by Leach and Scott (in press\(^2\)) who suggest that the notion of learning demand offers a tool for the design of teaching sequences. In their work Leach and Scott present the learning demand for a particular area of science teaching as identifiable from analysis of the science to be taught and research evidence of pupils’ everyday views of the science. Thus, for example, the learning demand for a particular topic might involve: developing an abstract model; differentiating between terms that are often conflated in everyday talk; emphasising the generalisability of a scientific theory and so on.

Whether the learning demand is large or small the teaching is planned to address the differences between everyday and scientific views. In conceptually demanding topics the disparity between common everyday notions and the science to be taught creates a large learning demand. Effective teaching would take account of the learning demand for a particular topic in identifying the teaching goals. In addition Leach and Scott (in press\(^1\)) present an argument for drawing on sociocultural perspectives of learning to inform the choice of pedagogical approaches. In particular this would inform the planning of patterns of discourse in the science lessons. Hence, the approach to designing the teaching sequence presented in this paper draws upon both research evidence about pupils’ commonly held, ‘everyday’ ideas about plant nutrition and sociocultural perspectives on learning.

A few research studies in science education have been reported where students make significant learning gains over their peers after following short teaching sequences whose design was informed by research evidence (e.g. Klaassen, 1995; Lijnse, 1995; Arnold & Millar, 1996; Tiberghien, 1997; Viennot & Rainson, 1999). In these studies, improvements in student learning are generally attributed to features of the teaching sequence. However, in most of the reported studies the teacher was centrally involved in developing the teaching approach. It is therefore possible that improvements in student learning arise as a result of changes in the way teachers conceptualise teaching and learning and deal with classroom interactions, rather than the teaching sequence and activities \textit{per se}. Theoretical tools exist for characterising teachers’ skills in explaining scientific ideas in ways that pupils understand (e.g. Ogborn et al., 1996; Scott and Mortimer, 2002). We draw upon aspects of these tools in this paper to examine the nature of the classroom interactions that result from this evidence-based approach to designing a teaching sequence. In particular we use the work of Mortimer and Scott (2000) on the nature of classroom interactions to examine the nature of the transition from a planned teaching sequence to the events that are staged in the classroom by 3 different teachers. The teaching is analysed in terms of both the conceptual content of the teaching as enacted and the nature of the interactions between the teacher and the pupils.

We are interested in the extent to which the nature of classroom interactions are similar when an evidence-based teaching sequence is implemented by different
teachers. To what degree are the interactions different for each teacher and to what extent are the interactions different from the teaching approaches designed into the sequence? It is our belief that the extent to which evidence about effective teaching approaches needs to be made explicit to the teacher, as opposed to being implicit in a new teaching sequence, has implications for the design of evidence based teaching sequences. It may be possible to improve learning by embedding evidence about effective teaching approaches in instructional sequences that result in implicit changes in the teacher's practice.

Overview of the study
The study was designed around two groups of case studies. The first (Development Case Studies) were designed to investigate the processes involved when researchers and teachers work together to develop and implement short teaching sequences about specific scientific topics drawing upon existing research evidence about teaching and learning. These teaching sequences were designed to address very specific learning goals relevant to the UK national curriculum for 11-16 year olds (DfEE 1999) and to be taught within the number of lessons usually allocated to the topic. During these Development Case Studies, evidence was collected about the ways in which the teaching sequences were implemented by different teachers, and the impact of the teaching sequences upon pupils’ learning (as measured against the identified learning goals).

The second set of case studies (Comparison Case Studies) were drawn from the same schools as the development case studies. Their purpose was to collect information about the teaching approaches typically used in these schools to teach the same topics as addressed in the Development Case Studies, and to assess the impact of these ‘traditional’ teaching approaches on pupils’ learning.

This paper will focus on the design and implementation of a teaching sequence for plant nutrition and address the following research questions:
1. What is the effectiveness of an ‘evidence-based’ approach to teaching plant nutrition, in terms of enhancing pupils’ learning?
2. What is the nature of teacher interactions in the implementation of the designed teaching sequence and to what extent are they similar for three case study teachers?

Research design and methodology

Design of the study
3 teachers worked in collaboration with 2 researchers on the design of the plant nutrition sequence. The teachers were selected as being enthusiastic and able, but having no special expertise in research on teaching and learning science concepts. Teachers who had undertaken a Masters or Doctoral degree in science education, or who had attended extended training programmes in science education, were not included in the sample.

These same teachers implemented the teaching sequence in their own classrooms as a part of their normal programme of teaching. All lessons in the sequence were video-recorded using a static camera. Teacher utterances were also audio-recorded on a
personal microphone worn by the teachers. Pupil responses to teacher utterances were audible via this microphone. In addition, researchers kept field notes during each lesson. These records provided data about the treatment of content by teachers during the implementation of the teaching sequences and the pattern of teacher-pupil interactions.

Similar video- and audio-data were collected for each of these teachers, working with the same classes, when they taught a lesson which was not part of the teaching sequence but which addressed a conceptually-rich area of the curriculum - for example, enzymes. The purpose of this was to provide some limited evidence about the kinds of teacher-pupil interactions that each teacher used during their normal practice.

Pupils’ pre-instructional knowledge and understanding was assessed immediately before the teaching sequence using diagnostic questions. Immediately after the teaching sequence their knowledge and understanding was assessed, against teaching goals identified for the teaching sequence, using a post-test. A delayed post-test was administered between 3 and 6 months after teaching had finished. Some questions were used in the pre-, post- and delayed-post tests. Other questions were only used after teaching, as they related to content that pupils could not reasonably expect to know about prior to teaching. Pupils were not given any notice that they would be asked to answer the diagnostic questions, in an attempt to reduce testing effects.

A Comparison Case Study was conducted for each Development Case Study. In each case, a group of pupils was identified in the same school as the Development Case Study, of the same age and ability (according to the school’s measures) as the group in the Development Case Study. It should be emphasised, however, that the 2 groups were not matched as statistically comparable on any indicator. In each case, the teacher in the Comparison Case Study was different from the teacher in the Development Case Study. In all Comparison Case Studies, pupils were required to complete pre-, post- and delayed-post tests as in Development Case Studies. In Comparison Case Studies, no data were collected about classroom interactions between the teacher and pupils, or about the content of the lessons.

Design of the teaching sequence
In the first instance, the teachers met together for a half-day in which ideas about learning demand and the significance of language in science teachers were presented. The UK national curriculum for science (DfEE 1999) was then examined by researchers and teachers, to identify broad areas of content that were conceptually rich and where a significant body of research on teaching and learning existed. Once the topic of plant nutrition had been agreed relevant literature, both on alternative conceptions in plant nutrition and teaching approaches that fitted the design of this study (Barker, 1985), was identified and reviewed by researchers. Learning demands were identified and these were discussed with the teachers. Teaching goals were then identified through discussion between researchers and teachers, and teaching activities were designed by researchers and teachers to address those teaching goals. Finally, the teaching activities were put together into lessons by researchers. Supporting guidance was written by researchers, following discussion with the teachers, about the staging of the lessons (including teacher-pupil interactions and useful questions to ask through which teaching goals could be addressed). This process is summarised in Figure 1.
The teaching scheme, in the form that was developed after implementation by the teachers, can be downloaded at:
http://edu.leeds.ac.uk/projects/lis/EpseTeachResources.html

Figure 1: The process of developing the teaching sequence

**Analysis of the data**

**Pupils’ learning**

The pre-, post- and delayed post-test questions asked pupils to explain what is distinct about plant growth (as different from animal growth) in a variety of contexts. In addition one of the post/delayed post-test questions asked pupils to predict the effect of limiting the amount of light on the number of starch grains in a leaf. The responses were coded for the extent to which pupils drew upon a scientific model of plant nutrition in their response. The response either included a consistent account of the model, an inconsistent or partial account of the model or no account of the model. The prediction for the starch grain question was coded as correct or incorrect.

The pre-test responses were used to check that there was no noticeable difference in the starting points of the case study and comparison groups in each case.

**The treatment of content by the teachers**

From the video and audio records of the lessons the sequence of conceptual themes, as enacted by the teacher, was identified. Similarly, from the lessons plans produced by the teacher group and researchers, the sequence of conceptual themes, as planned, was identified. The conceptual themes presented by the teacher were coded as (i) following the conceptual narrative of the planned teaching, (ii) recapping on
previously introduced themes or (iii) themes that were not part of the planned sequence.

**Patterns of teacher-pupil interaction**

Both the approach to teacher-pupil interactions and the focus of teacher-pupil interactions were categorised in the analysis.

The approach was categorised between dialogic and authoritative and between interactive and non-interactive drawing on a scheme developed by Scott and Mortimer (2002). Hence, the communicative approach during the lesson is shown as one of four categories:

<table>
<thead>
<tr>
<th>INTERACTIVE</th>
<th>NON-INTERACTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTHORITATIVE</td>
<td>Authoritative / Non-interactive</td>
</tr>
<tr>
<td>DIALOGIC</td>
<td>Dialogic / Non-interactive</td>
</tr>
</tbody>
</table>

*Figure 2: Four categories used to code teacher-pupil talk*

The focus of the interaction was categorised as one of three types:

- **Conceptual:** the focus of the interaction is on the conceptual theme of the lesson;
- **Descriptive:** the focus of the interaction is on techniques or observations or it is on factual knowledge that is not included in the conceptual theme of the lesson;
- **Management:** the focus of the interaction is on classroom management.

Thus teacher-pupil interactions were defined by both the nature of the interaction (authoritative/ dialogic, interactive/non-interactive) and the focus of the interaction (conceptual/ descriptive/ management).

From the lessons plans produced by the teacher group and researchers the pattern of teacher-pupil interactions, *as planned*, was defined.

From the video and audio records of the taught lessons the approach taken by the teacher in different phases of the teaching sequence was identified. Video and audio records of the lesson which was not a part of the teaching sequence were also analysed to identify the patterns of teacher-pupil interactions that each teacher used during their normal practice.

**Findings**
The learning outcomes, treatment of content by the teachers and patterns of teacher-pupil interaction are presented for each of the three case study teachers. The teachers are referred to by the pseudonyms Sam, Chris and Vic.

Learning outcomes
The pre-tests showed that, within each school, the developmental case study pupils and the comparison case study pupils were similar in terms of their pre-instructional knowledge and understandings.

After teaching, similar patterns of learning outcome were identified in all three developmental case study groups when compared with their comparison case study groups. In response to the post test question requiring a prediction about the effect of light on the number of starch grains in leaf cells, the developmental case study pupils were no more likely to make a correct prediction than the comparison case study pupils. However, when asked to give their reasoning, all three developmental case study groups showed a marked improvement over the comparison case study groups in the extent to which they were able to draw upon an appropriate and consistent model of plant nutrition in the explanations which they gave. This pattern was repeated across the post test questions. Figure 3 summarises the post-test responses for all three developmental case study groups and compares them with their comparison case study group.

Delayed post-test data for Sam showed that the gain in understanding of the model was sustained, in comparison with the comparison case study group. For Chris there was a noticeable slippage, although the delay in this case was much longer (6 months rather than 3 for Sam). No data were returned for the comparison case study group in Vic’s case and so no assessment of slippage could be made.

Treatment of content
The thematic content analysis of the lessons indicates that Sam followed a broadly similar sequence to the activities as set out in the teaching scheme and addressed the conceptual flow of the scheme as it was planned. The different lengths of time given to some of the activities reflect Sam’s adaptation of the activities to suit the ability of the group.

Chris followed a broadly similar sequence to the activities as set out in the teaching scheme and addressed the conceptual flow of the scheme as it was planned. The length of time given to some of the activities placed a different emphasis on some of the conceptual elements in the teaching sequence from the planned interventions. For example, Chris gave more emphasis in her teaching to the role of starch in the leaf and moved the activity that drew parallels between plant and animal nutrition to a homework activity. In discussions and presentations to the class Chris also focussed on concepts and knowledge that were not part of the conceptual sequence. In lesson 3 she makes a number of digressions to topics that are only tangentially related to the conceptual story of the intervention. In the final lesson there is a discussion with the whole class of some 5 minutes duration that moves away from the conceptual aim of the final intervention.

Vic followed a similar sequence to the activities as set out in the teaching scheme and addressed the conceptual flow of the scheme as it was planned. The different lengths
Figure 3: The extent to which a scientific model is used in responses to the post-test questions
of time given to some of the activities reflect Vic’s adaptation of the activities to fit the length of the lessons in this school. In some cases the activities were given considerably less time than in the planned sequence.

**Patterns of teacher-pupil interaction**

Table 1 provides a breakdown of the proportion of time the three teachers spent on different types of interaction within the teaching sequence, as compared to the proportion planned for in the teaching sequence. It also shows the time spent on each type of interaction during each teacher’s ‘normal’ teaching of a conceptually challenging topic.

<table>
<thead>
<tr>
<th></th>
<th>proportion of opportunities as planned (%)</th>
<th>proportion of implemented lessons (%)</th>
<th>proportion of comparison lesson (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sam</td>
<td>Chris</td>
<td>Vic</td>
</tr>
<tr>
<td>Pupil-pupil interactions</td>
<td>41</td>
<td>55</td>
<td>35</td>
</tr>
<tr>
<td>Teacher-pupil interactions</td>
<td>95</td>
<td>83</td>
<td>83</td>
</tr>
<tr>
<td>Conceptually focused authoritarian communication</td>
<td>34</td>
<td>27</td>
<td>19</td>
</tr>
<tr>
<td>Conceptually focused dialogic communication</td>
<td>38</td>
<td>46</td>
<td>17</td>
</tr>
</tbody>
</table>

*Table 1: A Comparison Of The Time Spent On Different Types Of Interaction*

All three teachers spent a high proportion of their time interacting with the pupils, but the ways in which they did this was showed several differences.

A high proportion of Sam’s interactions (75%) were conceptually focussed, with a preference for dialogic communication, more than matching the planned proportions. Field-notes and records of the lessons show that many of the dialogic interactions with pupils were of a skilled nature, using appropriate questions to support pupils’ developing ideas. A similar style of dialogic interactions was observed in the comparison lesson on enzymes.

In contrast, only 36% of the time was spent on conceptual content in Chris’s lessons. Many of the interventions focussed instead on the management of the class and the activity. Field-notes and records of the lessons show that many of the dialogic interactions with pupils were intended to keep pupils on task and encourage engagement with the activity, rather than to reinforce the conceptual aim of the teaching. A similar pattern of dialogic interactions was observed in the comparison lesson on enzymes.
In Vic’s lessons about half the interactions had a conceptual focus - less than was planned and slightly less than in Vic’s comparison lesson. A large part of the interactions were about supporting the completion of the activities by a very mixed ability group of pupils, many of whom spoke English is a second language.

Discussion and Conclusion
In all three developmental case studies the evaluation of the learning showed that the evidence-based interventions resulted in a better understanding of the concept of plant nutrition than in the comparison case studies. The process of designing a teaching sequence informed by research evidence on pupils’ everyday views of science and on socio-cultural perspectives on teaching and learning can result in improvements in pupil’s learning.

The issue then is the extent to which these gains might be attributed to the design of the teaching sequence (the translation of research ‘evidence’ into practice) rather than the teachers’ changing conceptualisation of teaching as a result of their engagement with the design process.

The structure, content and sequence of the activities was informed by evidence about pupils’ everyday views of science, research into teaching and learning and practitioner knowledge based on experience. The extent to which the three teachers understood the research basis of the final sequence was undefined. Discussions and interview data suggest such understanding was implicit, variable and (particularly in the case of Chris) tenuous.

For all three teachers implementation of the general structure and content of the teaching sequence, including pupil-pupil interactions, was close to the planned sequence. More variable was the extent to which the different kinds of interaction embedded in the design of the sequence, were implemented. In Figure 4 a comparison is made between the planned interactions, each teacher’s actual interactions within the teaching sequence and each teacher’s usual pattern of interactions as ascertained from their teaching of some other conceptually demanding topic. It is clear that although the teachers were staging the same sequence of activities their pattern of interactions varied. This variation appears to result from an interaction between each teacher’s usual teaching style and their perception of the interactions built into the planned sequence. When teaching the sequence both Chris and Vic spent much less time in conceptually focussed authoritative interactions than they did in their usual teaching but there was no matching increase in conceptually focussed dialogic interventions. In contrast Sam, who was usually very conceptually focussed but not authoritative spent more time during the teaching sequence in both authoritative and dialogic interactions, thus increasing even further the percentage of conceptually focussed interactions.

These findings from the plant nutrition sequence suggest that research evidence about effective teaching approaches does not need to be made explicit in order to be effective in enhancing learning outcomes. As a result, we would argue that it is possible to enhance good practice by embedding research evidence within the teaching activities of the sequence (for example, the use of extended conceptually focussed pupil-pupil interactions). If we are correct then teachers not engaged in the
design process, but willing to follow the sequence, should also be able to achieve learning gains. The next phase of this study plans to look at whether the teaching sequence can be used successfully by teachers who were not involved in the design phase.

Figure 4: Differences in the nature of the three case study teacher’s interactions (1 indicates the comparison lessons and 2 the intervention lessons)

Bibliography


