Developing teaching with an explicit focus on scientific thinking

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ABSTRACT This article describes an attempt to integrate teaching about an aspect of science 'content' with an aspect of the nature of science (NOS), through the development of a practical research-informed teaching module for use in key stage 3 (ages 11–14). The module concerned electrical circuits, and the NOS aspect focused on the role of models and analogies in scientific work. The module offers one example of a general approach that may be adopted in developing curricular schemes of work that build synergy between teaching about NOS and specific science topics. This article reports the outcomes of an evaluation of teachers using the module for the first time, and reflects on the limitations of randomised field trials for determining the efficacy of pedagogic innovations.

Developing teaching with an explicit focus on scientific thinking

This article discusses the design and initial 'field' evaluation of a secondary science teaching module for key stage 3 (ages 11–14). The first part describes how a module on electrical circuits was developed that integrated learning objectives relating to the nature of science (NOS) with physics content objectives, according to a pedagogic model incorporating research-informed principles for designing effective teaching. The second part reports the findings from an evaluation of the module in its first administration by teachers who had received limited professional development support, and considers some of the challenges of using 'experimental' designs to evaluate pedagogic innovations. School departments are invited to access and use the module in their courses but are warned that successful learning outcomes are likely to depend on the degree to which teachers are able to engage with the teaching approach built in to the module and to develop the skills to apply it.

Teaching about the nature of science

Science educators around the world have long argued that an authentic science education does not simply present students with some of the outcomes of science – the products, in terms of the current canonical theories, laws and models; rather, it has to give learners insight into the processes by which science proceeds, that is, the nature of science (NOS) (Matthews, 1994). Students who are taught a catalogue of accepted scientific ideas may consider science to be a largely complete subject where most things are known – a subject about facts. In reality, however, science is a highly theoretical subject which seeks to develop explanatory models that make sense of, fit with observations of, and support the development of predictions about, the natural world.

While some younger students may be highly motivated by collecting facts (e.g. about dinosaurs or comets, or the maximum observed speed of different land mammals), a subject that seems to be largely about learning existing information is unlikely to inspire older adolescents when they come to choose advanced studies or career options. In particular, the most gifted learners in science subjects (some, but not all, of whom may have an exceptional capacity for learning facts) are more likely to be challenged by a subject where there is room for dialogue, debate, interpretation and a need to cope with complexity and incomplete evidence (Taber, 2007). That is, the most able learners are likely to be engaged by science teaching that gives them a taste of the messy uncertainty of science in the making, and *all* students will benefit from seeing science as an open, ongoing, process with manifold career opportunities for making real contributions.

If school students are to experience authentic scientific modes of thinking, they need opportunities to critique scientific ideas that are open to question, rather than just being presented with the accepted canon of principles, theories and laws; they need to experience the making and interrogation of the 'cases' for and against mooted ideas, not just to be told existing 'verdicts'.

The science curriculum context

The work reported here took place in England, where the curriculum context has been ambivalent towards offering students deep engagement with the NOS in school science lessons. When first mooted, the English National Curriculum (ENC) was expected to embody a requirement to teach students about NOS that included exploring historical ideas and theories and why these had changed. Students were to be expected to consider how such ideas (often now considered inadequate, but which once had scientific respectability) related to their own thinking. It was recommended that opportunities to learn about such ideas should be '*part of normal science studies but supplemented on a limited number of occasions by activities specifically selected to promote key elements* …' (DES/WO, 1988: 70).

However, the final form of the National Curriculum presented science in terms of four administratively distinct attainment targets that reflected the three main disciplines of biology, chemistry and physics, and a separate target ('Sc1') seen to be about undertaking scientific investigations. This presentational divorce of scientific enquiry from the main bodies of scientific knowledge was compounded by the introduction of assessment requirements that led to the teaching of scientific processes in a way that often offered a caricatured version of straightforward experimental testing of simple hypotheses in laboratory conditions (Jenkins, 2000; Taber, 2008). That is, students were encouraged to adopt a notion of scientific investigation that offered an artificially simple view of one form of scientific enquiry (fair testing) but offered limited insight into, for example, the expansive programme of work that allowed Darwin (with Russel Wallace) to develop the theory of natural selection, or the creative thinking that led Einstein to propose relativity.

One attempt to reinvigorate the original intention of including teaching about NOS within the ENC was the revision of the requirements of Sc1 to put a greater emphasis on *the relationship between ideas and evidence in science*, which was reinforced by the National Strategy at key stage 3 (i.e. for 11- to 14-year-old students) – a major government investment in materials and professional development to support teaching. Considerable attention was given to this area by researchers and curriculum developers (for example, see the *School Science Review* theme issue, **87**(321) from 2006). Despite this, teaching and learning about NOS continued to be widely considered as a weaker area of secondary school science provision in England.

However, in 2007 the ENC for secondary science was completely restructured (QCA, 2007a, 2007b), offering a very different impression of the priorities and emphases expected in teaching school science. One feature was a considerable reduction in the specification of particular content. Another was a substantial rebalancing which gave aspects of NOS (referred to as 'How science works') at least as much prominence in the programme of study as the particular scientific ideas. There appeared to be a new context for planning science teaching which would be much more receptive to emphasis on the processes of science alongside the intellectual products of science (Toplis, 2011).

The epiSTEMe project

This curriculum shift coincided with the initiation of *Effecting Principled Improvement in STEM Education* (epiSTEMe), a new curriculum project looking to develop and test pedagogic approaches within science and mathematics education. The epiSTEMe project was sponsored by the UK Economic and Social Research Council (in partnership with the Gatsby Charitable Foundation, the Institute of Physics and the Association for Science Education) as part of a wider *Targeted Initiative on Science and Mathematics Education* (TISME). The epiSTEMe project, based in the Faculty of Education at the University of Cambridge, was designed to bring together ideas about effective science and mathematics teaching that had strong support from research, in order to provide a pedagogic model that could be used to design teaching modules (Ruthven *et al*., 2010). The intention was to develop some sample modules, which would then be evaluated using a randomised field trial design and which might act as exemplars for school departments developing curriculum modules. The design principles were drawn from reviews of existing research, and the approach was translated into teaching materials by inviting schools to be involved in designing, developing and piloting the modules. This was considered important to ensure that whatever was produced would be viable in 'typical' classrooms.

It was decided to target year 7 (age 11–12), the first year of secondary education in England. The team designed five modules. One was a generic introductory module that introduced key features of the epiSTEMe approach – particularly in relation to effective talk during student group work. This was considered important because one of the research-informed principles adopted was for effective teaching to be dialogic – where a range of different views and ideas are engaged with (see below). There were four subject-specific modules, two in mathematics and two in science (see Figure 1).

Ideally, students would study all five modules if epiSTEMe materials were used with both science and mathematics classes; however, modules were designed to stand alone (so, for example, the order in which a class met the two science modules didn't matter). Attempts were made to link some of the material taught in the science module on forces with material in the mathematics module on fractions, ratios and proportionality (shown as 'ratios' in Figure 1). This was considered desirable both from the perspective of helping students to make links across subject boundaries, and to encourage teaching in lower secondary science with a stronger emphasis on the mathematical representation of science concepts. A more detailed account of the forces module has been reported by Howe *et al.* (2014).

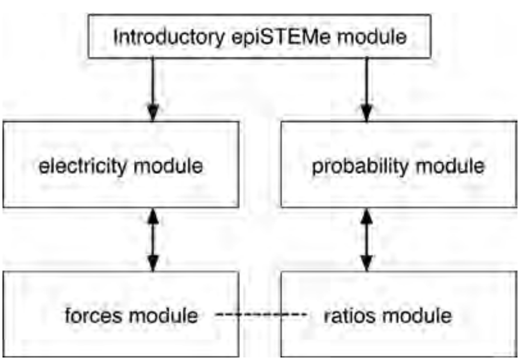

Figure 1 Modules developed during the epiSTEMe project

Principles adopted in designing the modules

A key feature of the epiSTEMe materials was that they were intended to engage learners in genuine dialogic discussion that allowed them to explore, compare and evaluate ideas – found to be an important factor in supporting effective learning. The modules were also set up so that there was balance and flow between student group discussion work and teacher-led whole-class discussion that would: (a) draw upon and examine alternative ideas suggested by students, and (b) scaffold student thinking towards the canonical scientific (or mathematical) perspective (Mortimer and Scott, 2003). This involves the teacher in dialogic modelling of authentic scientific thinking – that is comparing and evaluating students' ideas in terms of the scientific models and the empirical evidence produced during practical work. Another key feature was for the modules to be designed around engaging problem contexts. The pedagogic principles underpinning the project are discussed in more detail by Ruthven *et al*., 2011.

Science activities in the introductory module

The introductory module was intended for use by classes who would later be taught either the two science modules or the two mathematics modules (or, ideally, all four). It included alternative activities with a science or mathematics focus. The purpose of the introductory module was to allow students to learn the skills needed to engage in the dialogic activity in later modules. For science classes, there was an activity based around a concept cartoon (Naylor and Keogh, 2000) exploring the question 'Are nurses scientists?' and a discussion task in which student groups were provided with cards giving the characteristics of a number of elements that they were asked to classify as metals or non-metals based on a set of criteria. These activities were designed to allow all students to engage in the activities regardless of prior subject knowledge – one draws on an area of everyday knowledge (the work of nurses) and the other provides all the scientific information students need to undertake the task.

The concept cartoon showed a number of talking heads offering reasons for agreeing or disagreeing with the premise that nurses are scientists (Taber, 2014: 194) – relating to points such as the use of scientific equipment, not being based in laboratories, needing to collect evidence to solve problems, and so forth. The classification task was designed so that not all the elements could be unambiguously classified into one of the two categories. Thus, both tasks provided opportunities for genuine dialogue, where students could offer supported arguments for different points of view. The general guidance was that a group should seek to reach an agreed response where possible.

Both the science-specific activities included in the introductory module were designed to reflect features of NOS; the concept cartoon explored the issue of what makes an activity count as science; the sorting activity illustrated that many of the classification schemes that scientists impose on the natural world are imperfect – the idea of a dichotomy of metals and non-metals is a useful model of the nature of the chemical elements but, being a model, has a limited range of application.

The electricity module

Electricity was chosen as a theme for an epiSTEMe module in part because of long-standing recognition of widespread learning difficulties with this topic through the secondary phase (Shipstone *et al*., 1988). Another consideration was the availability of suitable materials that had already been subject to research and development and were considered to be effective (DCFS, 2008; Whitehouse, 2002) that could be incorporated into the module.

The epiSTEMe project ran from the end of 2008 to the start of 2013, so the early stage coincided with implementation of the 2007 revision of the key stage 3 science curriculum. The physics content to be taught at some point in the three years of key stage 3 was specified as (QCA, 2007a: 210):

The study of science should include:
3.1 Energy, electricity and forces

- *a) energy can be transferred usefully, stored, or dissipated, but cannot be created or destroyed*
- *b) forces are interactions between objects and can affect their shape and motion*
- *c) electric current in circuits can produce a variety of effects.*

Minimal explanatory notes supplemented this specification. In terms of electricity (3.1c) this amounted to (QCA, 2007a: 210):

Circuits: This includes current and voltage in series and parallel circuits.

Variety of effects: Electrical devices are designed to make use of a variety of effects caused by electric currents, including heating, chemical changes and magnetic effects.

This limited level of specification and guidance was in contrast to the previous curriculum, which not only included more detail in the statutory document but was also supplemented by a model scheme of work (QCA, 2000) and a framework document recommending how teaching should be developed over the three years (DfES, 2002).

In terms of the epiSTEMe principle that teaching should be based around engaging problem activities, the topic of electricity offered the option to look at the use of different kinds of transponders that could be included in circuits designed to meet various needs: that is, to focus on the technological applications of circuits. However, if the epiSTEMe approach is to be useful to teachers, it needs to be applicable to all aspects of the curriculum, including aspects known to present major learning challenges. It was therefore decided to develop the module around teaching the basic principles of electrical circuits (i.e. 'current and voltage in series and parallel circuits'), given the evidence demonstrating that students struggle to understand basic circuit principles.

The abstract nature of circuit ideas does not make them immediately suitable as the focus of engaging problem contexts. It was here that the adoption of NOS ideas was important. The new curriculum required students to develop an understanding of '*using scientific ideas and models to explain phenomena and developing them creatively to generate and test theories*' (QCA, 2007a: 208) as well as, *inter alia*, to '*develop and test ideas and explanations*', '*plan and carry out practical and investigative activities … in groups*' and '*evaluate scientific evidence*' (p.209). It was decided to have two parallel foci for the module: principles of electrical circuits, and the use of analogical models in science.

Teachers already regularly use analogies in teaching about electrical circuits (Taber, de Trafford and Quail, 2006). The epiSTEMe module was novel in that analogies and models would not just be used to teach circuit ideas, but would also be examined explicitly to explore how such models can be used as thinking tools in science. In effect, then, a module was designed that incorporated learning objectives about two distinct features of the curriculum –

ideas from physics relating to circuits and ideas from NOS that were found in the curriculum under headings such as ‘scientific thinking’ and ‘key processes’. The module was based on a notion of ‘epistemic relevance’ (Taber, 2015), where students would be challenged to make sense of real circuit phenomena in terms of alternative models.

A focus on scientific thinking and testing ideas

The electricity module was designed with group practical and discussion work at its core (a detailed account of the structure of the module has been reported by Taber *et al*., 2015). The overall plan of the module is shown in Figure 2, where the vertical arrow represents the timeline. The module begins by ensuring students have the basic knowledge to productively engage in the enquiry work on circuits (this phase is indicated by (a) on the right of the figure). There are then a number of cycles of activity (b), moving between group practical work set up to encourage discussion of student ideas, and teacher-led plenaries that draw on student thinking and steer them towards scientific understanding. Finally, there is a consolidation phase (c) where students are asked to evaluate the analogical models used in the module.

The module begins by discussing electrical circuits and the corresponding symbolic representations (circuit diagrams) and introduces general ideas about the role of models and analogies in the development of scientific ideas. Activities were designed to emphasise that using analogies with familiar systems as thinking tools to make predictions about a less familiar system is not just a pedagogic device (as often used in teaching the topic) but is also a feature of authentic scientific practice.

Students were introduced to three core analogies commonly used in teaching this topic – a rope loop model, a delivery van analogy and a physical simulation in which students themselves act as ‘charge carriers’. The core of the module comprised a sequence of predict–observe–explain activities (White and Gunstone, 1992) concerning core circuit ideas relating to current, potential difference and series and parallel circuits. Student groups were asked to use the analogical models to think about what would happen in particular circuits, before building the circuits and testing their ideas (see Figure 2). At each stage, the small-group practical work would be followed by a teacher-led plenary to draw out and explore students’ ideas about how the different models worked in order to make sense of circuits. At the end of the sequence of practical activities, student groups were asked to evaluate the models themselves (not simply as ‘right’ or ‘wrong’ but in terms of their potential value as ways of thinking about circuits) and undertook some synoptic revision activities in advance of a test.

Evaluation of the module

The epiSTEMe modules were developed with teachers who worked alongside the research team over several years and implemented iterations of the materials with their classes. These teachers acquired an understanding of the pedagogic approach and had opportunities to develop their skills in dialogic teaching. However, this amounted to a level of professional development beyond that generally available to teachers adopting new teaching resources.

The epiSTEMe project was evaluated through a randomised field trial in which volunteer schools that had not been involved in module development were assigned to the epiSTEMe or control conditions. Various measures were used to see how adoption of the epiSTEMe modules might influence learning and attitude compared with control schools, where the curriculum topics covered by epiSTEMe modules in year 7 (ages 11–12) were taught in the usual ways (Ruthven *et al*., 2016). In terms of the electricity module, this meant that classes following the epiSTEMe module were compared with other year 7 classes who were taught about electrical circuits by whatever means their teachers chose. As epiSTEMe was intended as an innovation that could be scaled up, the teachers asked to teach epiSTEMe materials were supported with only two days of professional development (which included information about the application of the research instruments, as well as the teaching approach and specific information about the modules). They were also provided with classroom materials and teaching guides. A major limitation of this approach is that the teachers undertaking epiSTEMe modules were following an unfamiliar scheme and potentially attempting to apply a challenging teaching approach for the first time but without any mentoring or ongoing modelling. The teachers working through this novel teaching module were compared with colleagues in control schools who were following established teaching routines.

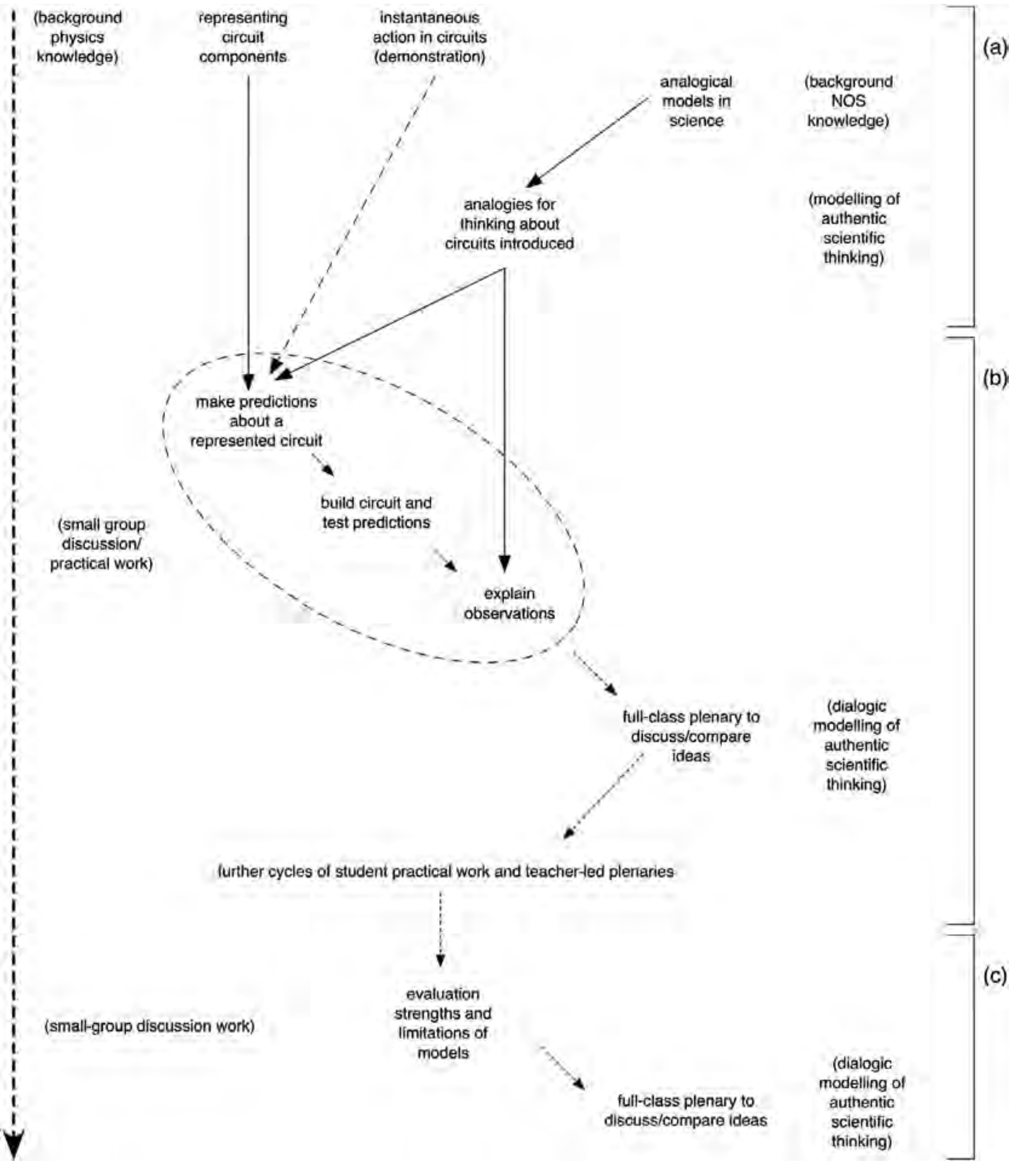

Figure 2 A schematic of the core design of the epiSTEMe electricity module

It has been suggested that educational research should aspire to randomised trials where feasible (Goldacre, 2013), although this view has been challenged (Phillips, 2005). There are well-known difficulties in applying experimental methods in education, such as knowing what does not need to be controlled or measured, the effects of participants' expectations about an innovation, and even that experiencing something new and different can often of itself have effects (Taber, 2013). The undertaking of a large-scale randomised trial was not without its challenges. A particular limitation with the evaluation of the electricity module was that it was decided to test student learning only in terms of their understanding of circuit principles and not in terms of their understanding of the NOS aspects (such as the role of models in scientific thinking) because the assessment had to be fair to the control classes where these themes were unlikely to have been emphasised. Similarly structured test papers with objective items (drawn from published national tests and previous research) were developed to be undertaken by the students immediately before being taught the topic, then immediately afterwards and finally some weeks later (i.e. pre-test, immediate post-test, delayed post-test; see Tables 1 and 2). Test items already in the public domain and widely used were adopted in order to avoid bias towards the intervention condition – an assumption that was checked statistically (Ruthven *et al*., 2016). The possibility of undertaking some kind of supplementary data collection to explore student responses to the NOS features of the module was discussed within the research team but this would have undermined the intention to set up a fair control condition by introducing something which could have been considered an additional intervention or learning opportunity that was not available in the control condition.

Findings

The data collected suggested that, overall, student learning gains about electrical circuits in classes undertaking the epiSTEMe module (see Table 1) were not so different from those in control classes (see Table 2). Indeed, statistical analysis of the data suggests that, on average, the epiSTEMe electricity module had slightly less effect on the learning of circuit principles than the standard teaching in control classes (Ruthven *et al*., 2016). This was disappointing, especially as it was not possible to see whether there were learning gains in terms of the NOS objectives, which might be considered to offer complementary student progress.

The limited amount of classroom observation possible during the project suggested that the teachers working with the epiSTEMe electricity module for the first time, who received limited professional development support, did not generally achieve the extent of dialogic teaching intended and required in the design of the teaching activities (Ruthven *et al*., 2016). This might reflect lack of confidence or fluidity in teaching an unfamiliar scheme designed to be presented in a novel style; alternatively, the results may suggest that the current module design needs some adjustments (or both). Unfortunately a randomised field trial, while being good at offering a controlled approach to testing the *overall* effectiveness of an innovation according to particular objective measures, is a blunt instrument for differentially teasing out the more and less effective features of a complex intervention such as epiSTEMe where the various aspects of the pedagogic model were integrated into the design of the teaching modules.

Table 1 Mean test scores (to nearest percentage point) on electrical circuits in 16 year 7 classes where the epiSTEMe electricity model was taught for the first time

Class code	Pre-test (%)	Immediate post-test (%)	Immediate gain (%)	Deferred post-test (%)	Deferred gain (%)
I_07_05_Sc	31	25	–6	28	–3
I_02_03_Sc	29	29	0	27	–2
I_11_03_Sc	19	24	5	25	6
I_03_01_Sc	32	46	13	45	13
I_07_03_Sc	35	49	13	51	15
I_01_02_Sc	23	35	12	42	19
I_12_04_Sc	26	46	20	46	20
I_12_03_Sc	17	33	16	38	21
I_03_02_Sc	21	37	16	44	23
I_05_01_Sc	30	56	26	55	24
I_08_03_Sc	38	54	15	62	24
I_11_04_Sc	27	53	27	50	24
I_10_02_Sc	18	40	23	43	26
I_08_04_Sc	19	50	31	46	27
I_01_03_Sc	23	50	28	52	29
I_06_02_Sc	27	63	36	60	34

Table 2 Mean test scores (to nearest percentage point) on electrical circuits in 12 year 7 classes studying the ENC topic of electricity in control schools

Class code	Pre-test (%)	Immediate post-test (%)	Immediate gain (%)	Deferred post-test (%)	Deferred gain (%)
C_07_04_Sc	32	35	3	36	4
C_07_03_Sc	30	42	12	41	10
C_02_02_Sc	46	55	9	57	11
C_06_01_Sc	44	53	10	56	12
C_11_04_Sc	19	35	16	32	13
C_12_03_Sc	21	35	13	38	16
C_06_02_Sc	31	50	19	50	18
C_01_03_Sc	44	54	9	67	23
C_04_02_Sc	31	54	23	58	27
C_10_03_Sc	32	61	29	61	29
C_11_03_Sc	24	60	35	56	32
C_04_01_Sc	30	65	35	63	33

Table 1 does show that the 'same' module can lead to very different outcomes with different teachers and classes. While most of the intervention classes (10/16) showed mean gains between the pre-test and deferred post-test of 20 percentage points or more, in two classes there was actually a small decrease in mean scores. Nearly half of the control classes (5/12) also showed gains of 20 percentage points or more, using whatever pedagogies and teaching materials were considered standard fare in those schools. It is striking how the spread of learning gains within the two conditions is quite similar, and the between-classes variation in learning gains is considerable in both the control and epiSTEMe groups. This indicates that judgements on whether a particular pedagogic approach can be considered effective (or not) are of limited value without specifying particular teaching and learning contexts.

Reflections on the development and evaluation of the module

Research inevitably invites further questions. It would be interesting to know the degree of learning about the use of models in scientific thinking that was facilitated by the module. It would also be interesting to know whether greater learning about circuits might be possible when teachers use the module for a second or subsequent time – or whether a more effective application of the module would require more extensive teacher support (at least initially). Our project development work and classroom observations suggest that a major shift in classroom behaviour may be required for many science teachers to achieve truly dialogic teaching that effectively explores and compares genuinely different perspectives. Research into teacher development suggests that such shifts are likely to be slow, depend on ongoing feedback and support (Guskey, 1986), and are best facilitated by working with colleagues who are also seeking to innovate their teaching in similar ways (Garet *et al.*, 2001).

As suggested above, randomised experimental testing as used in epiSTEMe (like the scientific investigations encouraged by the original ENC that similarly prioritised fair testing) offers limited insight to explain the disappointing evaluation outcomes. The electricity module may have been too ambitious or may have had some other flaws. It is known that many science teachers feel uncertain in teaching about aspects of NOS, and the teaching notes for the electricity module may not have provided sufficient support in this area. This may become clearer if there are further opportunities to field test (and perhaps further develop) the module in a research context that can focus on classroom interactions and teacher and student thinking – perhaps using the epiSTEMe project data as a means of benchmarking typical student gains in this topic.

Conclusions and recommendations for teachers

Teachers have been encouraged by the UK Government to get more involved in educational research, and in particular in randomised controlled trials (Goldacre, 2013). It is certainly valuable for teachers to work with academic researchers in the evaluation of educational innovations of the kind reported here. However, this study also reinforces the need for much broader forms of research in teaching (National Research Council Committee on Scientific Principles for Educational Research, 2002). The wide variation in learning outcomes across different classrooms teaching the 'same' module (see Table 1) indicates the need for detailed study of the processes of teaching and learning, in order to identify factors (and perhaps multiple interacting factors) that lead to a successful implementation of any pedagogic innovation. Such work calls for intimate involvement of classroom teachers in research.

One aim of the electricity module was to integrate teaching about NOS with teaching about traditional science content. Since the start of the epiSTEMe project, the curriculum context in England has shifted again. Some saw the 2007 ENC for science as a failed experiment forefronting 'How science works' over teaching science concepts. Nevertheless, the underlying principle that teaching *about* science is as important as teaching *some* science needs to be retained. Just as teaching (scientific) process without product fails to provide students with some of the major conceptual tools for making sense of their world, teaching (scientific) product without process fails to give students an authentic experience of the nature of scientific thinking. Whatever the merits of the particular attempt at marrying product and process represented by the epiSTEMe electricity module discussed here, it does reflect one approach to teaching canonical science in a context that emphasises scientific processes and scientific thinking alongside accepted scientific concepts, and, in doing so, offers practical work designed to be experienced by students as meaningful enquiry.

We hope that some teachers may be interested in exploring the epiSTEMe approach and perhaps evaluating the teaching materials for themselves. Documentation such as module teaching notes can be accessed via the project website. While the field evaluation suggested that teachers new to the approach should not necessarily expect improved learning outcomes on first teaching of the electricity module, the evaluation also suggested (Table 1 cf. Table 2) that the module allowed teachers to put a major emphasis on an NOS theme without compromising learning of the topic-specific science content.

Moreover, our experience working with teachers during the development of the epiSTEMe modules, and findings from previous research, suggests that the learning gains achieved by teachers who are completely new to working with the modules during the field trial are not indicative of what could be achieved in departments willing to commit to exploring the epiSTEMe approach and engaging with the pedagogic principles and teaching modules over an extended period. Teachers, like their students, take time to master and consolidate new learning. Many teachers will need to practise using the dialogic teaching approach that is fundamental to epiSTEMe in order to master the pedagogy. Teaching outcomes are likely to improve as teachers become more familiar with the materials and explore how best to tailor them for use with particular classes. Research into teacher development concludes that teacher innovation is facilitated by support and feedback, suggesting that an innovation such as epiSTEMe is most likely to be effective when adopted by members of a department working collaboratively and perhaps considering themselves as a research and development team.

The epiSTEMe modules were always intended as exemplars of how the teaching approach could be built into components of a department's scheme of work, which requires an understanding of, and 'feel' for, the design principles underpinning the modules. Teachers and departments interested in developing research-informed science teaching are invited to access the epiSTEMe materials and to evaluate and develop the approach in their own classes.

The teaching notes for the epiSTEMe modules are available from www.educ.cam.ac.uk/research/projects/episteme, which also offers contact details for anyone wishing to access the classroom materials.

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