Introduction

Since the late 1990s there has been concern that the ways in which inquiry is conducted in science lessons in schools runs counter to the ways in which scientists work; that is, it is not ‘authentic science’. Central to the ‘authentic science’ agenda is the notion that viewing inquiry as an inductive process, where theories emerge from evidence, is a flawed idea that needs correcting (Driver, Newton and Osborne, 2000). However, induction is a common approach used by science teachers, for example when supporting students with interpreting data collected through practical work, in order to draw a conclusion. Current perceptions of ‘the scientific method’ as reflected in school approaches to investigations, lead to distorted images of science that are contrary to how authentic scientists work (Windschitl, Thompson and Braaten, 2008) and the focus of this project is on developing resources that address such misconceptions.

Scientists work in ways where theory comes before and informs practical work. In school science it is often the other way round, where results are collated and the theory emerges through the conclusions drawn from the data. Scientists, in contrast, use their knowledge of the theory to predict the outcomes of experiments. They engage in questioning and discussion about how the data they have collected can be explained in terms of their theory-based models.

In essence then, the central focus of these resources is to support teachers in maximising the learning gained from practical work by adding **model-based inquiry** to the pedagogies they employ. These resources will provide an alternative to the consistent use of current inductive approaches to investigations by enabling teachers to support their students in developing concepts through using models and engaging in structured discussion, explanation and questioning about observations and data in the same way that professional scientists do. This ‘minds on’ approach (Abrahams and Millar, 2008) can be applied both before and after the ‘hands on’ component and illustrates how practical work can make a more telling contribution to learning and understanding science theory.

The key findings of the research

- Science should be presented as a process in which knowledge is socially constructed, and where discussion is central to the process (Driver, Newton and Osborne, 2000);

- Science classrooms need to offer opportunities for students to articulate reasons for supporting a particular claim; to attempt to persuade or convince their peers; to express doubts; to ask questions; to relate alternate views; and to point out what is not known. (Driver, Newton and Osborne, 2000);

- Too much practical work is focussed on *doing* rather than *thinking* and little or no time is set aside for discussion, argument and negotiation of meaning. (Hodson, 1998);

- Investigations are often simplified to a series of basic steps in order to enhance students’ success, leading to the mechanistic application of rote-learned questions to all investigation contexts, (Donnelly, Buchan, Jenkins, Laws, & Welford, 1996). This might imply that there is such a thing as a single ‘scientific method’ – something which is not consistent with the practice of scientists;

- Students spend too much time following recipes’ without understanding why they are doing it, and the quality of practical work is very varied (SCORE, 2008);
- Learning through practical work in an authentic science curriculum requires the acquisition of an acceptable understanding of what a model is and how modelling takes place (Gilbert, 2004);
- Model-based inquiry involves small group activity and discussion which engages students more deeply with the theory involved in practical work (Windschitl, Thompson and Braaten, 2008);
- The ‘scientific method’, observed in school investigations, has limited emphasis on explaining trends and patterns using science knowledge and where models/theories are considered, this is as an end product (conclusion) which is not talked about (Windschitl, Thompson and Braaten, 2008);
- Social practices shared by all scientists, including asking questions, developing and using models, analysing and interpreting data and constructing explanations contribute to a better science education which develops and improves student learning and offers a more accurate understanding of the ways in which scientists work (Osborne, 2011).

Research synopsis

Historically, in the UK, there has been a tendency for science teaching to be seen as a didactic practice, with teachers presenting lessons in largely the same way that they were themselves taught (Gallagher, 1991). Hodson (1998), in a critique of practical work in science, states that:

> ‘…the emphasis becomes concentrated on *doing rather than thinking* and little or no time is set aside for discussion, argument and negotiation of meaning’ (p94)

Abrahams and Millar (2008) make a clear distinction between the doing of the practical work, often referred to as ‘hands on’, and the thinking or ‘minds on’ activity which they claim is critical to enhance the learning of scientific knowledge and to gaining insight to scientific method as well as developing expertise in using it (Millar, 2009).

The introduction in 1989 of the Science National Curriculum gave a new status for practical work through focussing one of four key elements, Science 1, on Scientific Enquiry. However, this seems to have led to a narrow focus on investigations which were simplified by teachers to a series of basic steps in order to enhance students’ success (Donnelly, Buchan, Jenkins, Laws, & Welford, 1996). This ‘painting by numbers’ approach can lead to students mechanistically applying a set of common, rote-learned questions, in the same sequence, to all investigation contexts.

Changes in the National Curriculum offered 'How Science Works', the introduction of which enjoyed support from the National Science Strategy team and an extensive network of local authority-based science specialists. A report from SCORE (2008) suggested that 'good quality practical work promotes the engagement and interest of students' (p1) but found that there was no clear consensus within the science education community about the aims of such activity. Concern was expressed that students '…spend too much time following recipes' (p7) without understanding why they are doing it. The report concluded that the quality of practical work was very varied and recommended that a coherent programme of CPD on practical work was needed. This led to the establishment of the Getting Practical project (ASE, 2011) which offered CPD programmes aimed at improving the:

- clarity of the leaning outcomes associated with practical work
- effectiveness and impact of the practical work
- sustainability of this approach for ongoing improvements
- quality rather than quantity of practical work used.

Although **model-based inquiry** is embodied within the Getting Practical resources and there was an emphasis on the 'minds on' approach, these were, inevitably, a small part of the holistic focus on improvement in practical work targeted by the project.

Gilbert (2004) suggests that learning in an authentic science curriculum requires the acquisition of an acceptable understanding of what a model is and how modelling takes place. He also highlights the need for a well developed capacity in abstract thinking in order to:

> '… mentally visualise models… (and understand)… the natures of analogy and of metaphor which lie at the heart of a modelling approach (p115).

One approach to modelling (Keys et al. 1999) suggests explicit teaching about the nature of scientific enquiry by supporting students in developing explanations with their peers through a form of writing frame composed of generic questions such as 'What can I claim (conclude)?', 'Why am I making these claims?' and 'How have my ideas changed?' (p1069). A similar approach was proposed by Kenyon and Reiser (2006). They claim that their framework of questions can be used by teachers both to expose the nature of students' science understanding, including their misconceptions, and to develop the quality of evidence, and reasoning involved.

Windschitl, Thompson and Braaten (2008) offer a question framework which they call **model-based inquiry**. This is a system of small group activity and discussion which they claim engages learners more deeply with content through focussing attention on five key characteristics of scientific knowledge:

> '… that ideas, represented in the form of models, are testable, revisable, explanatory, conjectural, and generative… (and this leads to)…. the development of evidence-based explanations of the way the natural world works (p941).

In their work, models are seen as theories which generate hypotheses. These hypotheses can then be used to **make predictions** like 'If this is so, what would you expect to happen, when and why?’ and/or to **develop explanations** of observations. They contrast this approach with ‘the scientific method’ observed in schools which has limited emphasis on explaining trends and patterns using science knowledge and where models/theories are considered as an end product which is not talked about.

Osborne (2011) identifies eight teaching practices/pedagogies, which he refers to as ‘social practices shared by all scientists’ (p94). He suggests that these contribute to a better science education which offers students a more accurate understanding of the ways in which scientists work. Through engaging with the ‘practices’, students expose misconceptions to their teachers who in turn, use the ‘practices’ to address student ideas to develop and improve their learning. The practices include asking questions, developing and using models, analysing and interpreting data and constructing explanations; all activities that are central to **model-based inquiry**.

The implications for teaching approaches (including practical work)

Issues linked to design of resources

Scientists rarely work in isolation. Research is more of a social activity where small groups discuss, question, postulate, explain, disagree or propose alternative explanations and interpretations of data, based on what is already known about the problem. This style of collaborative and co-operative learning lies at the heart of this project where teachers may first explain what the ‘model’ of our understanding of the theory is, be that a definition, diagram, analogy, metaphor or equation and then support student learning through discussion and feedback, questioning that may involve cueing, corroboration or disagreement and through further explanation and coaching. In these ways teachers introduce their students to ways of talking and thinking about science practical work that they may not have met before. This style of approach illustrates what is meant by ‘brains/minds on’ in relation to practical work and is referred to as ‘scaffolding’ in the research literature as it is supporting students’ learning through making links with their existing knowledge.

From this it follows that the resources should provide opportunities for:

- Small groups of students to discuss questions that require them to use science theories (models) in explaining data collected through practical work; first and second hand data.
- Students to address questions which will assist them in developing explanations with their peers, such as
    - ‘Why did that happen?’ (requires an explanation that may expose misconceptions)
    - ‘Is this explanation… (given by students or the teacher)… supported by the data?’
    - ‘Based on what you know about… (topic x), what do you predict would happen when… /what data would you expect to collect if… you carried out an experiment like this?’

    - ‘How does the evidence collected support/contradict the theory?’
    - ‘How would you use this equation to design an experiment to check it is an accurate model/description?’ and ‘What results would you expect if it was a good model?’

- Teachers to present and engage students with authoritative accounts of science theories (models) in a range of different ways and then involve students in explaining and interpreting data using questions such as those exemplified in the above bullet point.
- Teachers to present models of different types (definition, diagram, analogy, metaphor, equation etc.).
- Teachers to encourage students to compare and critique models in the light of evidence collected in practical work (or second hand data).
- Teachers to support students in identifying different types of reasoning (Osborne, Erduran and Shirley, 2004).

The resources should distinguish clearly between **student discussions** (which are student-centred, though structured and monitored by teachers but not led by them) and **question and answer (Q/A) sessions** (which are teacher led). Model-based inquiry can include student discussions and Q/A sessions both in isolation and/or combination as, for example, where feedback from discussions can be linked with teacher comments which agree/disagree with discussion outcomes or provide further explanation.

A key question for developers to consider is whether a generic set of questions can be applied to a wide range of practical work, or whether model-based inquiries require a context dependent set of questions, or whether examples of questions provided in a limited range of contexts can provide a sufficient model for teachers to emulate in other contexts?

It could be that a generic question framework for teachers might offer ways of contextualising the nature of explanations to specific investigations as suggested by Windschitl, Thompson and Braaten (2008).

Some models require a developed capacity in abstract thinking in order to visualise, understand and explain them (Gilbert, 2004) and this raises issues about matching the age and ability of the target audience to model complexity.

Issues linked to teacher continuing professional development (CPD)

The approach embodied in these resources will require subtle changes to the pedagogies currently used by some teachers, while for others fundamental change will be involved. In addressing this issue the following points might be considered which could help teachers to locate their current practice in relation to this project’s approach:

- Teachers may need examples of the ways in which students are asked to engage with data from practical work and how this has changed in the last 40 years (from ‘experiment to prove that…’; through recipe following in response to answering a closed question such as ‘Is light necessary for photosynthesis?’; to the student-planned Sc1 ‘investigation’ which follows closely a recently completed class practical where a very similar procedure to that expected from the student was carried out in a marginally different context). The nature of teacher and student involvement at each of these examples can be made explicit.

- A worked example showing how model-based inquiry differs from current perceptions of an investigation might be helpful – examples of both approaches set in the same context could help to make the contrasts stark.

- Using examples from the existing practical chemistry/biology/physics websites and showing how they might be modified using a model-based inquiry could be powerful.

Other CPD issues might include:

- Developing teachers' concept of a 'model' (Gilbert, 2004);

- Developing teachers' perceptions of Q/A sessions, which although a common pedagogy in school science lessons, is very different from the specific style of questioning linked to practical work that is envisaged here;

- Supporting teachers in managing and organising peer discussions and the pedagogies associated with these activities;

- Directly addressing teachers' perceptions that there is a risk of reinforcing erroneous ideas when presenting and discussing misconceptions in an attempt to persuade students to believe the accepted scientific explanation (Osborne, 2001);

- Supporting teachers in identifying different types of reasoning (Osborne, Erduran and Shirley, 2004);

- Supporting teachers in distinguishing between claims, warrants, rebuttals and counter-claims (Osborne, Erduran and Shirley, 2004).

References

Abrahams, I., and Millar, R. (2008). 'Does Practical Work Really Work? A study of the effectiveness of practical work as a teaching and learning method in school science'. *International Journal of Science Education*, 30 (14), 1945-1969.

ASE (2011). Getting practical – Improving Practical Work in Science programme.

Driver, R., Newton, P., and Osborne, J. F. (2000). 'Establishing the norms of scientific argumentation in classrooms'. *Science Education*, 83 (4), 287-312.

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

Gallagher, J. J. (1991). 'Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science'. *Science Education, 75* (1), 121–133.

Gilbert, J. (2004). 'Models and Modelling: Routes to More Authentic Science Education'. *International Journal of Science and Mathematics Education*, 2 (2), 115-130,

Hodson, D. (1998). 'Is this really what scientists do? Seeking a more authentic science in and beyond the school laboratory'. *In:* Wellington, J. (Ed.), *Practical work in school science: which way now?* London: Routledge, pp. 93 -107.

Kenyon, L. and Reiser, B. (2006). *A Functional Approach to Nature of Science: Using Epistemological Understandings to Construct and Evaluate Explanations.* Paper presented at the American Educational Research Association, San Francisco, California.

Keys, C., Hand, B., Prain, V. and Collins, S. (1999). 'Using the Science Writing Heuristic as a Tool for Learning from Laboratory Investigations in Secondary Science'. *Journal of Research in Science Teaching.* 36 (10), 1065–1084.

Millar, R. (2009). *Analysing practical activities to assess and improve effectiveness: The Practical Activity Analysis Inventory (PAAI)*. York: Centre for Innovation and Research in Science Education, University of York.

Osborne, J. (2001). 'Promoting argument in the science classroom: a rhetorical perspective'. *Canadian Journal of Science, Mathematics and Technology Education*, 1 (3), 271-290.

Osborne, J. (2011). 'Science teaching methods: a rationale for practices'. *School Science Review,* 93 (343), 93 -103.

Osborne, J., Erduran, S. and Shirley, S. (2004). *Ideas, evidence and argument in science: In-service training pack*. London: Nuffield.

Science Community Representing Education (SCORE) (2008). *Practical work in Science: a report and proposal for a strategic framework*. London: Gatsby Technical Education Projects.

Windschitl, M., Thompson, J. and Braaten, M. (2008). 'Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations'. *Science Education,* 92 (5), 941-967.