Model-based inquiry and practical work – an introduction

This set of resources exemplifies ways in which practical work can be used alongside a pedagogical approach known as 'model-based inquiry'.

Model-based inquiry *is based on the* ***generating****,* ***testing*** *and* ***revising*** *of* ***scientific models****. It is different to typical school science investigations, in that it is centred round a collaborative and co-operative style of learning and places emphasis on the explanatory model.*

How this introduction is organised

Quick start guide:

The quick start guide set out the bigger picture of what model-based inquiry involves and how it can relate to practical work in science.

For more detail about the points raised in the quick start guide go to the relevant sections which follow:

Section 1: An 'authentic' approach to learning science

Section 2: How is model-based inquiry different to the way investigations are typically carried out?

Section 3: The Practical Work for Learning resources and transferring the approach.

Section 4: Research findings

References

Quick start guide to model-based inquiry

What is model-based inquiry?

Practical work is used as a method of teaching for a range of purposes (e.g. skill development, application of concepts). Model-based inquiry is based on the generating, testing and revising of scientific models, with the aim of developing evidence-based explanations of the way the natural world works. This is the way in which many scientists work (Windschitl et al., 2008), so model-based inquiry is both a teaching approach and an authentic representation of how science produces explanations (see Figure 1).

Model-based inquiry is different to typical school science investigations, in that it is centred round a collaborative and co-operative style of learning and places emphasis on the explanatory model. In a model-based inquiry students are expected to:

✓ Use knowledge of a model to predict the outcomes of experiments, and explain their reasoning.

✓ Test predictions against evidence collected by observation and experiment.

✓ Engage in questioning and discussion about how the data they have collected can be explained in terms of the model.

✓ Develop explanations of scientific phenomena from models.

For school science, model-based inquiry provides a framework for engaging students with the science content and ideas behind a practical activity. This kind of ‘minds on’ activity is critical to enhance students’ learning of scientific knowledge and insight into how scientists work (Abrahams and Millar, 2009).

Models in science

Models are a mentally visualisable way of linking theory with experiment. They enable predictions to be formulated and tested by experiment (Gilbert, 1998).

There are many different types of model. These include

- Consensus model – a model which is widely accepted by the scientific community. For example the Bohr model of an atom, or a mathematical relationship between variables.

- Historical model – a previous consensus model which has been replaced by a new, more useful model. For example the plum pudding model of an atom.

- Mental model – an individual’s internal representation (in the mind) of information in a form which is useful for solving problems. For example a flow diagram of an ecosystem.

- Teaching model – a model which has been specifically produced to teach a difficult concept. For example, ripple tanks used to teach about waves.

Introducing models

See the PowerPoint presentation: 'Scientific models?'

What does model-based inquiry look like in the classroom?

The summary on the following page has been prepared using a range of literature on the subject, and is designed to introduce you to the different elements of a model-based inquiry lesson and how these might be structured together.

THE TEACHER

In the classroom:

Plan to establish effective discussions and critical thinking:

- Encourage students to share their own ideas (mental models) for explaining the phenomenon, where possible.
- Listen to discussion – ask open questions which *facilitate* pupils' thinking and idea expression.
- Consider the composition of groups, and how this could affect group discussion.
- Present the consensus model at an appropriate point in the lesson (see 3 possible lesson structures outlined below).
- Facilitate the critical evaluation of models by students, by challenging misconceptions as they arise and presenting alternative / more sophisticated models for the students to analyse the data against.

THE LESSON

LESSON STRUCTURES		
Structure 1 -Students' **mental models** are basis for predictions -Data collected -Consensus model presented after data collection -Critical analysis of both models	**Structure 2** **-Simple or incomplete model** is basis for predictions. -Activity to engage deeply with model -Critical evaluation and refinement of simple model	**Structure 3** -Recalling a **previously taught model** and analysing its limitations -Developing a more sophisticated model -Applying the new model in a different context

MODEL-BASED INQUIRY – Central to the lesson

Teacher scaffolding
(Reiser, 2004; Wood et al. 1976)

Small group discussion
(Brown et al. 1989)

Model-based inquiry
(Windschitl et al. 2008)

Checking prior learning

Listening to and promoting dialogue

Questioning

Social construction

Applying, understanding, evaluating and refining models

Using assessment for learning opportunities to identify and challenge misconceptions.

- Why did that happen?
- Is this explanation supported by the data?
- How does the evidence support/contradict the model?
- What results would you expect if it was a good model?
- How would you check it is a good model?

Use of group talk to analyse the effectiveness of models, compare and contrast models and explain data, and refine models in light of new data.

Section 1: An 'authentic' approach to learning science

Scientific inquiry is one of the processes used to develop scientific knowledge. However, it does not necessarily represent an effective pedagogic approach for learning scientific theories in school science.

School science investigations are often reduced to a series of easy to follow steps (Donnelly et al., 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. It is also often assumed that theories will emerge from the evidence; that by collecting data and analysing it, students will be able to draw conclusions that explain the data. This is known as 'induction'. Research has shown that viewing inquiry as an inductive process is a flawed idea. We need theories to make the link between data and explanations, and students need access to these theories if they are to be expected to develop explanations (Driver et al., 2000).

The diagram below (Fig. 1) presents a more authentic model for scientific reasoning. Through observation and measurement, scientists collect data on the real world. Scientists also generate models to explain the behaviour of the real world, which they can use to make predictions. They then compare their predictions with the data. If there is agreement between the prediction and the data this increases the scientists' confidence in the model which provides an explanation for this particular phenomenon. If there is disagreement between the prediction and the data, scientists might question the model, the reasoning that led to the prediction, or the quality of the data. If the model is brought into question it will be revised and the process begins again.

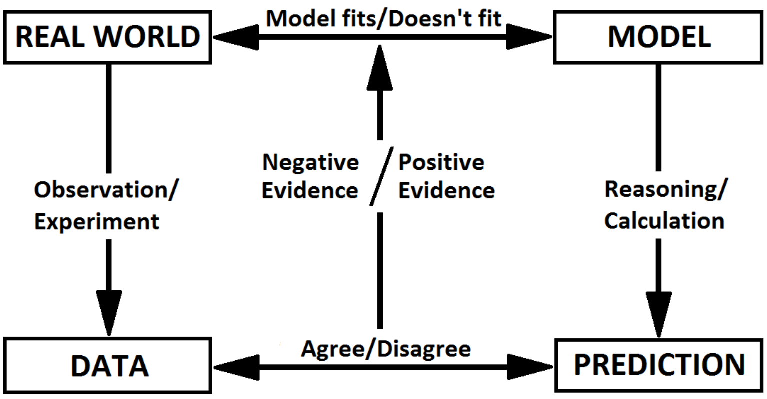

Fig. 1 Giere's 1991 diagrammatic representation of the interaction between reasoning, theory, and argument in the development of scientific ideas.

Key ideas from this framework for scientific reasoning

- Explanations of scientific phenomena are developed from theories or models based on the theories. This is a creative process. There is no direct route from data to explanation.
- Predictions are tested against evidence derived from observation and

experiment.

- Knowledge of a theory or model is used to predict the outcomes of experiments. Theory comes before, and informs observations and experimental planning.

- Scientists engage in questioning and discussion about how the data they have collected can be explained in terms of their theory-based models.

- 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 model-based inquiry.

Section 2: How is model-based inquiry different from the way investigations are typically carried out?

Model-based inquiry illustrates one possible approach to what is meant by 'minds on' in relation to practical work.

General teaching approaches used in model-based inquiry

It is useful to think about when and how you will use question and answer sessions, and how you will prompt students' discussions. Developing these discussions may be familiar in school science lessons, but what is suggested here is very different. It is very specific, with questioning linked to practical work and the models which help to explain data.

Support in managing and organising peer discussions and the pedagogies associated with these activities can be found in the argumentation resources in this project. Here are some strategies you might consider:

- Encourage students to share their own ideas (mental models) for explaining the phenomenon, where possible.
- Listen to discussions and ask open questions which *facilitate* pupils' thinking and idea expression.
- Consider the composition of groups. Use strategies for facilitating discussion and feedback such as think-pair-share, envoys, 30 second group presentations.
- Present the consensus model at an appropriate point in the lesson (this may be at the start to compare with another competing model, after data collection to compare against students own model or at the end of the lesson to compare to pupils revised models.
- Facilitate the critical evaluation of models by students, by challenging misconceptions as they arise and presenting more sophisticated models for the students to analyse the data against.

Strategies used in model-based inquiry

A model-based inquiry lesson includes:

		
Teacher scaffolding: Teacher-supported prompting, dialogue and plenaries, making links with prior learning. (Reiser, 2004; Wood et al., 1976)	**Small group discussion:** Social construction of knowledge. (Brown et al., 1989)	**Model-based inquiry:** Understanding and applying the model(s), which needs to be presented explicitly. (Windschitl et al., 2008)

Introducing models

See the PowerPoint presentation: 'What is a model?'

All three components are essential within a model-based inquiry learning sequence. Through these students are introduced to new ways of talking and thinking about science practical work.

Key conversations

The diagram below (Fig. 2) from Windschitl et al. (2008, p.955) summarises the key conversations within a model-based inquiry. As students gain experience with guided forms of investigation, they become more competent inquirers by 'internalising' the conversations – eventually asking themselves the relevant questions without prompting.

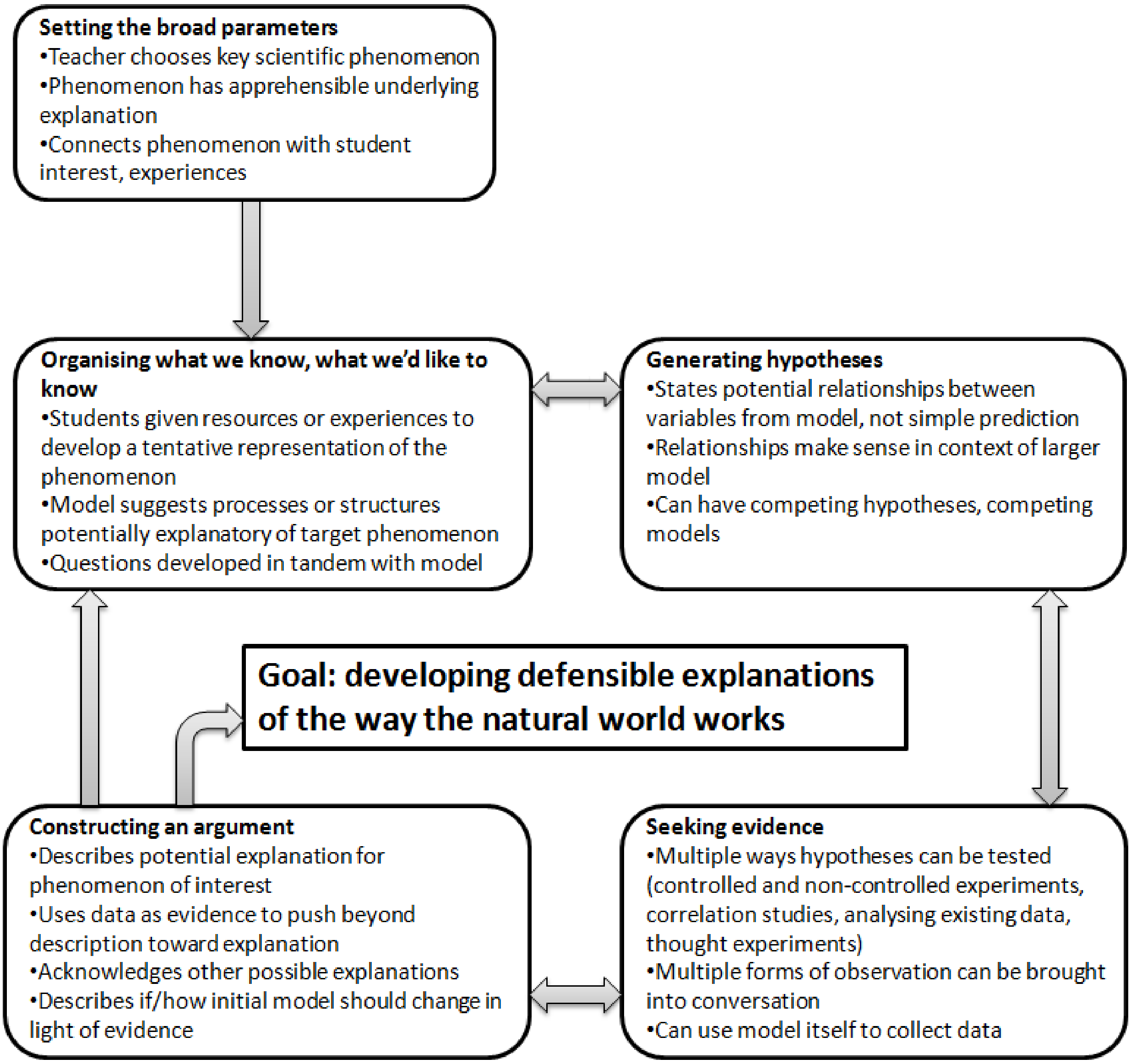

Fig. 2 Developing defensible explanations of the way the natural world works

(Windschitl et al., 2008)

The scientific model can be introduced and used at different points in an inquiry; before data collection to frame a prediction and the design of a suitable experiment to test the prediction, or after data collection to frame the analysis of the results. The teacher's role is then to support student learning through discussion and feedback.

Small group discussion

Small group discussions should be student-centred; structured, prompted, monitored and followed-up by teachers but not dominated by them. Teacher-led question and answer sessions may include scaffolding through cueing, corroboration or disagreement, further explanation and coaching.

Small group discussion and teacher-led question and answer sessions can be used in isolation or in combination. For example, feedback from discussions can be linked with teacher comments which evaluate and reflect on discussion outcomes or provide further explanation.

Scaffolding learning

Questions which might be used to involve students in explaining and interpreting data, and comparing and critiquing models in light of evidence include:

- 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 model?
- How would you use this equation to design an experiment to check it is an accurate model/ description?
- What results would you expect if it was a good model?

Section 3: The Practical Work for Learning resources and transferring the approach

The quick start guide identifies three possible structures for model-based inquiry lessons. Each of these is exemplified by one or more of the Practical Work for Learning lessons.

Structure 1

Key features

Students use their own ideas (mental models) to make a prediction about the outcome(s) of an experiment.

A consensus model is presented once students have collected data / made observations.

Students' own models and the consensus model are critiqued in terms of their potential for predicting and explaining outcomes.

Exemplar lessons

- **Gathering evidence to test models of colour vision *and***
- **The combustion of iron wool**

Small group discussion

In the colour vision lesson, students work in small groups to make a prediction in the form of a map of colour vision for their field of view. They test their prediction and refine their model in light of the evidence. Finally they consider the relationship between their map of colour vision and the consensus model for the arrangement of cones in the retina.

In the iron wool lesson, students work in small groups to predict what will happen to the mass of iron wool when it burns. They watch a teacher demonstration which shows that the mass increases. This outcome is often very surprising for students whose experiences of burning usually result in a loss of mass. Students are supported in using the particle model and the equation for the reaction to explain the increase in mass.

Scaffolding learning

There is evidence that struggling with a problem before being told the solution may 'prime' students' thinking, making them more receptive to the explanation of the problem, even if their own interpretations are not accurate (Schwartz and Bransford, 1998). As tools for reasoning, mental models are a product of science education which should be explicitly acknowledged. Constructing mental models and the new connections that they elicit (Kahneman and Tversky, 1982) is a role of scaffolding in inquiry learning.

How do I transfer this approach to new contexts?

This approach is not suitable for all kinds of science practical. To decide whether or not to use this approach, you should consider whether students can be expected to hold or develop their own mental model.

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. For example, from their own experience, students might have a useful (if incomplete) mental model about how an object will fall compared with a lighter object. They may not have a useful model for bonding that will support explanations of energy changes in chemical reactions.

Structure 2

Key features

A simple or incomplete model is presented first for students to use to predict experimental outcomes.

Activities are devised to make sure students engage deeply with the model.

The model is critiqued and refined to fit data from the experiment.

Exemplar lesson

- **Using a 'pot model' to represent osmosis**

Small group discussion

This lesson involves students collaborating to construct a pot model to represent osmosis between a plant cell and surrounding solution. The pot model is related to a 2-dimensional model, and these are used to predict outcomes of an experiment. Simple models can help students to imagine what might be going on 'beneath the observable surface' as they manipulate variables and make observations in their experiments. This gives purpose to the manipulations and provides a perspective for thinking and talking about the observations (Solomon, 1999).

Scaffolding learning

When a simple model is provided that is within students' current understanding, it can be refined through cognitive conflict. If the simple model does not provide a sufficient explanation for the data, a better model is needed. Cognitive conflict has been used in science education as a method to bring about cognitive shifts since the 1980s (Driver et al., 1985). Teachers can help to support the process where students refine their models, by highlighting the added explanatory or predictive power of the new model.

How do I transfer this approach to new contexts?

This approach is not suitable for all kinds of science practical. To decide whether to use this approach, you should consider whether students have previously been introduced to incomplete or naïve scientific models. For example, students have been taught about energy and electricity in primary and early secondary education. Their models must be refined further if students are to use them to explain the phenomena they will engage with in more advanced science lessons. Processes which appear in the curriculum at various stages and at varying levels of complexity provide other possible examples, such as photosynthesis.

Structure 3

Key features

Recalling a previously taught model and examining its limitations.

Developing a more advanced model.

Applying the more advanced model in different contexts.

Exemplar lesson

- **The effect of concentration on rate**

Small group discussion

In this lesson sequence, students discuss and evaluate collision theory as a model for rate of reaction and move towards a mathematical model, the rate equation, which enables quantitative predictions to be made. They determine the rate equation for the reaction of marble chips with hydrochloric acid, and analyse data to deduce the rate equation for other reactions.

Scaffolding learning

Teachers can scaffold the transition to use of refined models to predict and explain phenomena.

How do I transfer this approach to new contexts?

This approach is not suitable for all kinds of science practical. To decide whether to use this approach, you should consider whether the concept is one in which the consensus model presented to students is different at different stages of their learning. A model is good one if it helps to explain what you want to explain, but as students progress more complex models are often needed. By exploring the limitations of previous models, students will be able to see why the previous model is now insufficient and why a new model is needed.

For example, osmosis is normally taught by considering solutions separated by a partially permeable membrane. When osmosis between plant cells is introduced, a more sophisticated model must be introduced to take account of the osmotic pressure applied by the plant cell walls. Other examples include how understanding food chains precedes food webs, and how an overview of transfer of respiratory gases precedes the model of reactions inside a red blood cell leading to uptake and release of oxygen at the appropriate locations in the body.

Section 4: Research findings

What does the research have to say about…

… model-based inquiry and authentic approaches to science inquiry?

- A definition from Quintana et al. (2004) synthesises how the literature describes scientific inquiry: 'the process of posing questions and investigating them with empirical data, either through direct manipulation of variables via experiments or constructing comparisons using existing data sets' (p. 341).
- The 'scientific method', observed in school investigations, has limited emphasis on explaining trends and patterns using science knowledge; where models/theories are considered, this is as an end product (conclusion) which is not talked about (Windschitl et al., 2008).
- School science 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 et al., 1996).
- 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).

…the importance of small group discussion?

- Science should be presented as a process in which knowledge is socially constructed, and where discussion is central to the process (Driver et al., 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 et al., 2000).
- 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 and Patterson, 2011).
- Often the collection of data and its presentation dominate practical lessons compared with discussion about the inferences from the experiment. Leach and Scott (2002) suggest that these types of opportunities for internalisation through discussion need to be built into any teaching sequence that involves an empirical inquiry.

…'minds on' practical work?

- 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).
- 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).

- Model-based inquiry involves small group activity and discussion which engages students more deeply with the theory involved in practical work (Windschitl et al., 2008).
- Struggling with a problem before being told the solution may make students more receptive to the explanation of the problem, even if their own interpretations are not accurate (Schwartz and Bransford, 1998).

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