TEACHING ABOUT SCIENCE

A THEORETICAL MODELS: ELECTROMAGNETISM

This is a lesson aimed at helping students to develop their understanding of the role of theories in science, using James Clerk Maxwell's model of magnetic vortices as an example.

Teachers' notes

Resources for students and teachers (separate download)

download from www.nuffieldfoundation.org/aboutscience

OHT A0.1 Aims of the lesson
OHT A1.1 Observable phenomena <—> Abstract ideas
Student sheet A1.2 Catapult effect
Teacher resource sheets A2.1A, A2.1B Background information (2 sheets)
OHT A2.2 Maxwell says … , A2.3 Maxwell's model
Teachers' sheet A2.4 Maxwell's model, with key
Student sheet A2.5 The story of Faraday, Maxwell, and field theory (2 sheets)
Student sheet A3.1 A kinetic model of gases and temperature

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A THEORETICAL MODELS: ELECTROMAGNETISM

TEACHERS' NOTES

FOCUS

Whilst *observable phenomena* often provide the starting point for new scientific understandings, scientists can use *abstract ideas* and analogies to develop new theoretical models.

By using an analogy to link a poorly understood area of science with a well understood area of science scientists are able to draw upon old resources to solve new problems.

Scientists need to be able to recognise those analogies that are useful. Useful analogies might link areas of science previously considered as separate. Useful analogies can also generate predictions that can be tested.

RATIONALE

This teaching sequence aims to develop students' ideas about the role of theoretical models in science. Students tend to believe that theoretical models emerge directly from data, and that features of the theoretical model correspond directly to features in the real world. This teaching sequence aims to encourage students to recognise that scientists develop theoretical models using creative analogies, in addition to experimental data and observations, and that many features of theoretical models do not correspond directly to features in the real world. The teaching sequence also aims to show that theoretical models developed in this way are useful because they enable scientists to make links with other areas of science, and generate testable predictions.

The main part of the teaching is set in the historical context of Maxwell's model of magnetic vortices, and its relation to Faraday's model of magnetic field lines. Maxwell used a very visual analogy in his consideration of electromagnetic effects; an analogy which was also very fruitful in drawing upon insights from other areas of science (hydrodynamics), making links with other science concepts (speed of light) and generating testable predictions. As such this 'historical story' provides an excellent context for discussion about the role of analogies in theoretical models. Furthermore, the ideas of Maxwell and Faraday are readily accessible to AS/A2 level science students at the level presented in the teaching.

AS/A2 LINKS

This teaching sequence could be used equally effectively in either an AS course or A2 course.

Within an AS course it might be necessary to allow a little longer for some of the activities. Some of the material used is complex and students early in their AS course would need support in dealing with it.

Using this sequence as part of an A2 course enables links to be made with many other models such as those in the sections of the criteria: current; atomic and nuclear physics and quantum physics.

Teaching about the role of theoretical models features in the QCA subject criteria:

'AS and A level specifications in PHYSICS should encourage students to:
• develop an understanding of the link between theory and experiment;
• understand how mathematical expressions and models relate to physical principles.'

Maxwell's model of magnetic vortices does not feature in the physics criteria. However, it does relate to the following content areas:
• Molecular kinetic theory in the AS (QCA specification reference 3.7.3)
• Fields and magnetic effects of currents in the A2 (QCA references 3.12 and 3.13)

KEY SKILLS

The activity gives students the opportunity to gain competence in the following key skill areas:

Communication Level 3

C3.1a Contribute to a group discussion about a complex subject.

Portfolio evidence of this could be in the form of a note from an assessor (the teacher) who has observed the discussion and noted how the requirements of the unit have been met, or an audio/video tape of the discussion.

TEACHING SEQUENCE

Introduction (brief)

Resources OHT A0.1 'Aims of the lesson'.

Points to raise This lesson will be rather different from many science lessons (not much writing and lots of discussion). Students should think and talk!

Students are being given the opportunity to step back and consider 'What is this thing called science?' In particular the lesson will consider 'What is the purpose of theoretical models in science and how are they developed?'.

Students will be expected to get involved in paired discussion and feed back their ideas to the whole class (link to key skills).

In this opening presentation the teacher introduces the main aims of the lesson, emphasises the unusual nature of the lesson (history of science, no writing and lots of discussion), and highlights how learning about theoretical models links to other areas of the physics course.

Commentary Trials of this teaching sequence have shown that it is important to state briefly why you think that it is important that students learn about the nature and purpose of theoretical models and how they are developed.

Activity A1 (15 minutes)

The teaching sequence begins with a short teacher presentation and paired student activity which aims to communicate the difference between **abstract ideas** and **observable phenomena/objects**. Two physics contexts are used: the 'catapult' effect in electromagnetism and the kinetic theory of gases.

Aims At the end of this activity students should:
1.1 recognise the distinction between observable phenomena/objects and abstract ideas;
1.2 understand that abstract ideas are a key feature of many theoretical models in science.

Teacher presentation of A1 (5 minutes)

Resources: OHT A1.1 'Observable phenomena <—> Abstract ideas'

In this part of the lesson you will use the example of kinetic theory to illustrate the idea that a scientific understanding of an observable phenomenon/object involves the use of 'abstract' ideas.

Instruction	**Commentary**
Describe the following phenomenon stressing the key features (highlighted). When an inflated balloon is **cooled down** the **volume of the balloon decreases**. Scientists explain this phenomenon by using the kinetic theory of gases. This theoretical model relates the temperature and volume of the gas to the behaviour of '**billiard ball-like' particles** of gas.	In this example the **cooling down** and **decrease in volume** are observable phenomena, the **billiard ball particles** are an abstract idea. The use of balls as an analogy for the particles of a gas enables the scientist to borrow from the Newtonian view of the world to understand the relationship between volume and temperature in a gas.
Use the 'Observable phenomena/objects <—> Abstract ideas' grid (OHT A1.1) to categorise each of the three highlighted features in the range from observable phenomena/objects to abstract ideas	Other abstract ideas presented in this lesson are: • magnetic lines of force; • Maxwell's vortices; • Faraday's electromagnetic 'vibrations'. The use of the term 'observable' here includes phenomena/objects observable using sophisticated measurement/observation instruments. It may be necessary to steer students away from thinking of 'abstract ideas' as phenomena/objects that cannot be seen with the naked eye.

Student activity A1 (5 minutes)

Resources: student sheet A1.2 'The catapult effect: observable phenomena <—> abstract ideas'

Instruction	**Commentary**
Instruct students to decide which of the features highlighted on the sheet are observable phenomena/objects and which are abstract ideas. Groups record their conclusions on sheet A2.1 Observable phenomena <—> Abstract ideas.	This activity works best in groups of 2 or 3. Trials have shown this activity to be effective if kept very brief. Students should be encouraged to give particular attention to 'magnetic field lines'. It is helpful to draw the discussion to a close before students have exhausted all their ideas, but ensure they have chance to discuss the 'magnetic field lines'; these exemplify what we mean by abstract ideas.

Dealing with the discussion A1 (5 minutes)

Instruction	Commentary
Take feedback from each group on their decisions about the three highlighted features. Develop their answers to highlight the teaching aims 1.1 and 1.2.	This feedback should be used to refer back explicitly to the teaching aims of this activity

Link with the next activity

Pose the question 'Are all abstract ideas equally good?'. You could give a limited, unhelpful or absurd analogy here to show that not all analogies are useful; for instance, electricity is like the sand in an egg timer; they both flow.

Activity A2 (25 minutes)

Using the resources provided, the teacher presents the main features of Faraday's ideas about magnetic field lines and Maxwell's model of magnetic vortices. Working in pairs, students then discuss their responses to a set of questions about these two models. Finally, the teacher takes feedback from the students and gives the appropriate responses for each of the questions.

This activity builds on the distinction between abstract ideas and observable phenomena/objects introduced in activity A1, by illustrating two ways in which abstract ideas can be useful. Faraday's model used abstract ideas that gave some insights into the phenomenon, but were not particularly fruitful. Maxwell's model was developed using the abstract idea of vortices in fluids. This theoretical model enabled him to draw upon the mathematics of hydrodynamics, and also make an astonishing link between electromagnetic effects and the speed of light: two phenomena considered as totally unrelated at the time.

Aims At the end of this part of the lesson students should:

2.1 recognise that not all analogies in science are equally useful;

2.2 recognise that by using an analogy to link a poorly understood area of science (e.g. magnetism) with a well understood area of science (e.g. vortices in hydrodynamics) scientists can draw upon old resources to solve new problems;

2.3 be aware that useful analogies may link areas of science previously considered as separate (e.g. electromagnetism and light).

Teacher presentation of A2 (10 minutes)

Resources

Teacher resource sheets A2.1A and A2.1B (A2.1B consists of two sheets)
OHT A2.2 'Maxwell says …'
OHT A2.3 'Maxwell's model'

Instruction	Commentary
The teacher presents the story of the development of Maxwell's field theory. The teachers' resource sheets provide an overview of the story. The key aspects of the story illustrate the aims of activity A2 – these should be emphasized. A more detailed background is provided (sheet A2.1B). It is helpful to be familiar with this before the lesson – see student sheet A2.5. The OHTs relate to specific parts of the story – see the overview on sheet A2.1A.	OHT A2.2 contains quotes from Maxwell and a picture of him. OHT A2.3 shows an adaptation of Maxwell's analogy. It should support the presentation but students do not have to understand it in detail. The key on sheet A2.1A is for your use, and need not be presented to the students.

Student activity A2 (10 minutes)

Resources: Student sheet A2.5 'The story of Faraday, Maxwell, and field theory'

Instructions	Commentary
Instruct the students to discuss the questions on sheet A2.5 in pairs/groups of three. These are repeated below. **1** Faraday made an analogy between magnetism and lines of force that transmitted vibrations. In what way was this useful? **2** Maxwell used an analogy between magnetism and spinning vortices in a liquid. In what way was this useful? **3** How were scientists persuaded that Maxwell's analogy was useful?	Trials suggested that less able students are not able to think beyond the workings of the visual model. **They should be encouraged to focus on the latter part of the story, which demonstrates the usefulness of the model.**

Dealing with the discussion A2 (5 minutes)

Instruction	**Commentary**
Take feedback from each group on their answers to the questions. Develop their answers to highlight the teaching aims 2.1 and 2.2. The commentary provides 'sophisticated' answers to the questions which teachers could point students towards in the discussion.	**1** Faraday's theories about lines of force initiated a new way of looking at fields which did not assume action at a distance. **2** Maxwell's model predicted that there would be transverse vibrations of electromagnetism propagated through the medium of the model. When the speed of these was calculated using the model it was almost exactly the same as light. This seemed too much of a coincidence and from it Maxwell inferred that light is transmitted in the same way as electro-magnetism. He anticipated the unification of light and electromagnetism. This was remarkable at the time. **3** Following publication of the mathematical model several scientists set out to obtain experimental evidence to support the predictions of the model. In some cases they were successful. Details are beyond the scope of this activity. (See teacher resource sheet A2.1B.)

Link with the next activity

Pose the question 'Are there other areas of physics in which abstract ideas have been useful?'

Activity A3 (15 minutes)

The teaching sequence ends with a short activity in which students show how the kinetic theory of gases can be used to make a prediction: that there is a minimum temperature. This final activity is designed to be used either as a student discussion task or a homework activity.

The purpose of this activity is to reinforce the idea that **testable predictions** arise from theoretical models that are based upon abstract ideas. This gives a third way of deciding whether or not a particular abstract idea is useful or not in addition to those in aims 2.2 and 2.3.

Aim at the end of this activity students should **3.1** be aware that useful analogies can lead to theoretical models which generate testable predictions.

Student activity A3 (10 minutes)

Resources student sheet A3.1 A kinetic model of gases and temperature

This activity could be set as an individual task for homework. If used in this way, a follow-up would be needed to focus students on the activity A3 teaching aim.

Instruction	Commentary
Instruct students to complete student sheet A3.1 in pairs/groups of three. They are asked to use the kinetic model of gases to: • describe how the kinetic model of a gas predicts that there is a minimum temperature; • consider any other predictions the model might support.	The students should be able to describe their reasoning for predicting a minimum temperature in a way that refers to features of the model. For instance, the particles cannot move less than 'not moving', so the model predicts there must be a minimum temperature when the particles are stationary. In trials some students gave arguments based in mathematical reasoning. In this case they should be asked to draw links between their mathematical statements and the analogies in the model. Other predictions could include: • rates of diffusion depend on temperature; • pressure depends on temperature; • volume changes with temperature; • reaction rate varies with temperature.

Dealing with the discussion (5 minutes)

Instruction	Commentary
Take feedback from each group on their answers to the two questions. Develop their answers to highlight the activity A3 teaching aim.	

Closing the teaching sequence (5 minutes)

Resources OHT A0.1 'Aims of the lesson'

The sequence ends with a recap of what the students have learnt following the aims presented above. At this point links to other models in the physics course can be made. It can also be stressed that these ideas about theoretical models will be revisited in future lessons in the physics course.

Points to raise	**Commentary**
Go through OHT A0.1 which gives learning aims for each of the three activities. Emphasise the key points. Make links to other models in the physics course, or perhaps from other science courses that the students might be following. Physics examples include: • current; • atomic and nuclear physics; • quantum physics; • electricity – an area which has generated lots of analogies with varying degrees of usefulness. Say how you will be looking for students to draw on the ideas here in later lessons.	Trials of this teaching sequence have shown that: • it is critical that sufficient time is left for a meaningful summary; • students need to feel that they have learnt something from this lesson; • teachers need to emphasise the links between what students have learnt and the rest of their physics/science course(s).