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Chapter 10

USING MODELS IN TEACHING AND LEARNING SCIENCE

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ABSTRACT

Models can be excellent tools to help explain abstract scientific concepts and for students to better understand these abstract concepts. A model could be a copy or replica, but it can also be a representation that is not like the real thing and can provide insight about a scientific concept. Models come in a variety of forms, such as three dimensional and concrete, two dimensional and pictorial, and digital forms. The features of models often depend on their purpose: for example, they can be visual, to show what something might look like, dynamic to show how something might work, and or interactive to show how something might respond to changes. One model is often not an accurate representation of a concept, so multiple models may be used. Students’ modelling ability has been shown to improve through instruction and with practice of mapping the model to the real thing, highlighting the similarities and differences. The characteristics of a model that can be used in this assessment include accuracy and purpose.

Models are commonly used by science teachers to describe, and explain scientific concepts. Pedagogical approaches that include students using models to make predictions and test ideas about scientific concepts encourage students to use models for higher order thinking processes. This approach relates the use of models to the way scientists work, reflecting the nature of science and the development of scientific ideas. This chapter will focus on the way models are used in teaching; identifying pedagogical processes to raise students’ awareness of characteristics of models. In this way, the strengths and limitations of any model are assessed in relation to the real thing so that the accuracy and merit of the model and its explanatory power can be determined.
INTRODUCTION

Models are commonly used in teaching science to motivate learners, promote engagement and to provide authentic, hands-on activities and links to the real world. Models have multiple values in teaching and learning science: teaching the scientific concepts, the scientific process and the nature of science, as presented in Table 1. Teaching science can be challenging for teachers in many ways, such as being confident and knowledgeable in the subject matter, organising equipment for the classroom activities, and planning lessons so that students have opportunities to develop an understanding of scientific concepts (Hackling, Peers, and Prain, 2007). Models serve as descriptive and explanatory tools - they are central in supporting both students and teachers in developing conceptual understandings of scientific ideas.

Modelling is central to learning - and modelling scientific concepts provides opportunities for students to think scientifically. This chapter discusses the nature of models and modelling, explores how and why models can be used in teaching science and provides a description and justification for the model-based pedagogical approach, teaching with models.

WHAT IS A MODEL?

A model is commonly thought of as a copy or replica; but a model can include a variety of representations such as scale models, symbolic models, mathematical models, theoretical models, maps, diagrams, and simulations (Harrison and Treagust, 2000). Models are useful tools that can provide detail about ideas and concepts that are not readily visible or accessible for various reasons, such as being too small to be seen, too large to be seen, too dangerous or based on abstract theories.

Models can be two or three dimensions including concrete, virtual, and diagrammatic models. Models may or may not provide a depiction that is a likeness of the real thing; furthermore they are often depicted in terms of something else with which the learner is more familiar. The use of concrete models, pictorial representations, animations and simulations has been shown to be beneficial to students' understanding of scientific concepts (Tasker and Dalton, 2006). Modelling is the mapping of a model to a target such as the scientific idea or concept, and in this way, they are useful explanatory tools to understand phenomena.

<table>
<thead>
<tr>
<th>Use of a Model</th>
<th>Understanding the Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Models represent scientific concepts and act as descriptive and explanatory tools. They can provide a focus for further hypothesising and testing of ideas.</td>
<td>the scientific concepts, the scientific subject matter</td>
</tr>
<tr>
<td>By using a model, the learner develops the skill of modelling.</td>
<td>the scientific process</td>
</tr>
<tr>
<td>Modelling is an authentic scientific practice. So by using models, learners can communicate their understanding of scientific ideas and hence model scientific processes and scientific thinking</td>
<td>the nature of science.</td>
</tr>
</tbody>
</table>
The visualisation provided by models can be instrumental in helping learners construct a personal mental model of the target - the scientific idea or concept. A mental model is a “psychological representation of real, hypothetical, or imaginary situation” (Johnson-Laird, Girotto, and Legrenzi, 1998, p. 1) and as learners assimilate new information provided by the various representations including models they build internally a personal mental model of the concept being studied in their own schema. Schnitz, and Bannett describe the use of pictures and text in learning “as the process of analogical structure mapping between a system of visuo-spatial relations and a system of semantic relations” (2003, p. 146). It is through the expressed model, that the extent of the mapping and depth of learning becomes apparent. The expressed model is communicated by an individual through action, speech or writing (see Figure 1).

**Types of Models**

There are a variety of typologies for models, based on a variety of criteria such as their purpose, role, and attributes to name a few. Harrison and Treagust (2000, pp. 1014-1017) proposed:

- Scientific and teaching models
- scale
- pedagogical analogical model
- Pedagogical analogical models that build conceptual knowledge
- iconic and symbolic models
- mathematical models
- theoretical models
- Models depicting multiple concepts and processes
- maps diagrams and tables
- concept process models
- simulations
- Personal models of reality, theories and process
- mental models
- synthetic models

Boulter and Buckley (2000) proposed a typology of models based on the mode of the representation, (three-dimensional, verbal, visual, mathematical or gestural), and the attributes of the representation that may be quantitative/qualitative, static/dynamic, or deterministic.

![Figure 1. The relationship between real models, mental models and expressed models.](image-url)
Figure 2. Examples of models: 
a) Scale model of the heart.
b) Scale model of a motor
c) Student made model of an alarm on a door.
d) Teaching model—a professionally made diagram of a cross section of a flower model.
e) The use of a lever to model movement in a crocodile jaw—a scale model.
f) Dynamo.
g) A model of the earth in centre of universe.
h) A model of DNA.
i) A model using levers to create movement.
 j) A model volcano.
Chittleborough and Treagust (2009) adapted the typology proposed by Gilbert and Boulter (1995) - distinguishing teaching, scientific mental models and expressed models. Krajick looking at chemistry models used the properties of the models - such as the structure, interactivity, dynamic nature, quantitative aspects and macroscopic attributes (Krajick, 1991).

Typologies are constructs that can be useful in highlighting properties and making comparisons. Typologies may be better suited for the particular situation such as specific discipline or particular use of models. The examples of teaching models presented in Figure 2 and Table 2 illustrate the usefulness of the multiple typologies.

Table 2. Mode, Accuracy and Purpose (MAP) for each model in Figure 2

<table>
<thead>
<tr>
<th>Model</th>
<th>Mode</th>
<th>Accuracy</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Scale model of the heart</td>
<td>3D Static, qualitative</td>
<td>Made to scale</td>
<td>Visual representation,</td>
</tr>
<tr>
<td>b. Scale model of a motor</td>
<td>3D Dynamic quantitative</td>
<td>Accurate - like a real motor</td>
<td>To show how a motor works</td>
</tr>
<tr>
<td>c. Student made door alarm.</td>
<td>3D Dynamic quantitative</td>
<td>real alarm, very accurate</td>
<td>To show how a simple alarm works</td>
</tr>
<tr>
<td>d. A cross section of a flower</td>
<td>2D Static quantitative</td>
<td>Much larger than reality</td>
<td>Shows relative sizes of flower parts</td>
</tr>
<tr>
<td>e. Model of lever action in crocodile</td>
<td>3D Dynamic, qualitative</td>
<td>Not like the real thing,</td>
<td>To show the use of levers to make the crocodile mouth</td>
</tr>
<tr>
<td>f. A model of a dynamo</td>
<td>3D Dynamic, quantitative</td>
<td>Accurate</td>
<td>To show how to produce electric current from moving water.</td>
</tr>
<tr>
<td>g. A model of the earth</td>
<td>3D static, quantitative</td>
<td>Not like the real thing,</td>
<td>To provide a three dimensional perspective</td>
</tr>
<tr>
<td>h. A model of DNA</td>
<td>3D quantitative, static</td>
<td>Not accurate</td>
<td>Provides an image of the three dimensional structure</td>
</tr>
<tr>
<td>i. A model using levers to create movement</td>
<td>2D Dynamic, quantitative</td>
<td>Not accurate</td>
<td>to use lever to create movement</td>
</tr>
<tr>
<td>j. A model volcano</td>
<td>3D Dynamic, quantitative</td>
<td>Not at all accurate</td>
<td>Visual representation</td>
</tr>
</tbody>
</table>

STUDENTS’ PERCEPTIONS OF MODELS

Many students view models only as copies of the scientific phenomena (Grosslight, Unger, Jay, and Smith, 1991) and their understanding of the role of models frequently is seen as being simplistic (Treagust, Chittleborough, and Mamiala, 2003). For example students and teachers commonly consider models to be an exact replica of the real thing; that models are accurate and will not change over time (Treagust, Chittleborough, and Mamiala, 2004; Van Driel and Verloop, 2002). Students see scientific ideas being explained by one model only; and they often confuse the model with the content by considering the model as a new thing to learn - not a means to explain what has to be learnt (Gilbert, 1997; Grosslight, et al., 1991). Within this scenario, the use of models can lead to students developing misconceptions. Generally, students’ understanding of the role of models improves with increasing years of
schooling. Some secondary students learning introductory organic chemistry with a model based approach, failed to appreciate or recognise that they were using the ball and stick models in predictive and testing ways, modelling as they are used in authentic scientific processes (Treagust, et al., 2004).

Models are used to provide a picture of abstract and unfamiliar science concepts and ideas. Models require mapping the target to the model, and when the target is known e.g. the movement of the diaphragm and the lungs, can be mapped to a model of balloons in a bottle (Figure 3). This mapping is logical and plausible for the learner, and is based on their personal experience, however, when the target is unknown e.g. electrons in an electric circuit being modelled with moving dots representing electrons, in an applet (Figure 4), the mapping becomes more difficult for the learner to accomplish and the model has greater importance.

Figure 3. A model of how the lungs work.

Figure 4. Circuit construction kit - PhET applet simulating an electric circuit (http://PhET.colorado.edu/ accessed 1/8/2011).

The model of the electric circuit requires the learner to link the moving dots and the light glowing; connecting the concept of sub microscopic charged particles (dots) carrying energy through a conductor and being transformed into the light being emitted. These unfamiliar scientific concepts and ideas can affect the credibility of the models. Al-Balushi (2011) has
researched students’ perceptions of the credibility and authenticity of models according to a measure of the degree of abstractness and distinguished four levels:

- Certainty level - where the target is considered to be real and there is good evidence that the model is accurate (e.g. photo).
- Imaginary level: where the target is considered to be real, but the model shows what scientists imagine it to be.
- Suspicious level - where the target is considered to be real but the model is not real nor accurate,
- Denial level: where the target is not considered to be real (Al-Balushi, 2011)

Al-Balushi (2011) reported how as students used more complex and abstract models their confidence in the model waned: “the overall students’ epistemological perceptions across grade levels showed a decrease in the certainty level and an increase in the imaginary level” (p.599).

This is true for chemistry where the dual characteristics: the real and visible characteristics of the macroscopic level and the real and “invisible” characteristics of the sub-microscopic level collide creating suspicion in learners (Chittleborough and Treagust, 2008).

**Teachers Perceptions of Models**

Teachers’ level of understanding of models has been described as limited because they have a simplified understanding of models and modelling in science (Van Driel and Verloop, 2002). Similarly pre-service teachers have reported to have “uninformed views of the role of models and modelling in science” (Crawford and Cullin, 2004, p. 1399). Teachers with limited background science knowledge in science content areas and in the history and philosophy of science can find teaching with a model focus challenging (Henze, Van Driel, and Verloop, 2007).

Teachers require an understanding of the role, purpose and use of models in teaching and learning science content, the scientific process and the nature of science. Teacher education about models and teacher experience with using models is critical if the teaching with a model focus is to impact on student’s learning. Henze, Van Driel and Verloop (2007) reported improvement in teacher’s knowledge about the use of models and modelling when teaching with a model focus, but acknowledged the need for teachers to reflect on the nature of models, and to plan how modelling is used as a learning activity and have time to try out new ideas.

**What Is Modelling Ability?**

Modelling requires the user to relate the model to the target, and to use the model to form hypotheses, test ideas and make predictions about the target using the model. Not recognising a model as an analogue and not being able to link the model to the target suggests an inability to model. Modelling is a skill that is often assumed, however modelling ability is not an
innate skill. Students may be experienced modellers – such as copying parent behaviour or playing with models of familiar items, but unable or inexperienced in modelling in the context of abstract science concepts. Grosslight et al., (1991) distinguished three levels of modeller:

- Level 1: “the model is thought of as a toy or simple copy of reality”. (Grosslight, et al., 1991, p. 817)
- Level 2: students “realise that there is a specific explicit purpose that mediates the way the model is constructed”. (Grosslight, et al., 1991, p. 817)
- Level 3: “the model is constructed in the service of developing and testing ideas rather than as servicing as a copy of reality itself” (Grosslight, et al., 1991, p. 818).

A student’s level of modelling is not fixed or predetermined and develops with instruction. Modelling ability is closely aligned to reasoning ability and higher order thinking skills (Harrison and Treagust, 2001). Model-based activities depend on the learners ability to model in order to use models for reasoning and thinking processes such as, forming hypotheses, making inferences, identifying variables, perceiving trends and patterns, providing reasons and explanations. While modelling is an important skill in science, it is not usually taught directly to students as a skill, rather it is taught within and alongside science content, and runs the risk of being overlooked. In their study, Grosslight, et al. (1991) based their classification of students’ modelling abilities on six dimensions: the role of ideas, the use of symbols, and the role of the modeller, communication, testing and multiplicity. These dimensions are evident in a student’s ability to:

- identify the target of the model and assess the Mode (form), Accuracy, and Purpose
- transfer from one model or representation to another.
- recognise the strengths and limitations of each model.
- use models for testing, predicting and evaluating ideas.
- use multiple models in congruent ways.

Using models can be challenging, motivating and engaging for students. Ownership of self-made models can provide opportunities for creativity, understanding, as well as highlighting misconceptions. To use the models as effective thinking tools, they must involve the integration of new knowledge with existing knowledge. The models can use familiar materials to present new knowledge. By analysing and reflecting on the parts of the model, its role, purpose and links to the target are emphasised. The scientific content being modelled does affect the appropriate mode that we use. Questions that inform the underlying theoretical frameworks and which can achieve this objective include the following:

- What are the attributes of the model in terms of Mode, Accuracy, and Purpose?
- Is the model logical?
- Does the model explain the concept that you are trying to learn?
- Is the model useful? – Do I understand the concept better because of the model?
- Are there other models that could be useful?
Inherent in answers to these questions is an assessment of the model as an explanatory tool—separate from the content or concept that is being taught. This refers to the model being integral to the development of scientific ideas in the process of science.

**Models and the Nature of Science**

Models are used to help construct scientific knowledge, however students' appreciation of this idea is reported to be unclear (Al-Balushi, 2011). Modelling is a core process of the scientific method and as such it is worthwhile attempting to understand what students think about models. The link between using models in science classrooms and their use by scientists in the development of scientific ideas can be tenuous and unconvincing, and there seems a heavy reliance on individual teachers to highlight and build these links. This is unlikely if the teachers themselves are without a good foundational knowledge of the nature of science. Teachers with naïve conceptions perpetuate these perceptions among their students. As reported by Loxley (2009), a teacher ignorant that her oversimplification of scientific ideas was not accurately portraying the complexity of nature of science. Loxely describes “the consequences of this naïve understanding of the nature of science can be a conceptually barren approach to science learning” (Loxley, 2009, p. 1618).

Australian students from Year 8, 9, 10 11 and first year university responded to a survey about models and modelling (VOMMS) (Chittleborough and Treagust, 2009). The data is presented in Table 3. In addition students provided reasons for their choice. The data revealed that many students considered models an important tool in the process of science. Some students could identify the roles of models in the nature and process of scientific ideas. In response to item 4, many students explained their understanding of the relationship between fact, theory and model. Examples of such responses include, “having an accurate model will emphasise change of future models having to adapt to new theories” and “the model needs to clearly support and help explain a theory – that’s what they’re designed to do”.

Many students reasoned that Science was based on fact, confirming the importance of the factual basis of science – with comments such as, “Science is based on facts as we know them and accepted until proven otherwise” and “Science is not a negotiable subject and should not be based on opinionative information but on fact”. The fixed and constant nature of facts is tempered with the realisation that facts can change, and many comments by students revealed that they were aware of this. The responses to the VOMMS instrument indicate that the students support the relationship with models as the starting point for the development of theories, and models taking up an intermediary position between observed reality and theory (Gilbert and Osborne, 1980).

**Models in the Process of Science**

Modelling is one part of the scientific processes - in which problems are posed, ideas explored, questions asked, experiments conducted, data analyzed and interpreted and re-evaluated leading to further experiments, possible conclusions, new theories being proposed, explanations being tested etc. The process of science is iterative and it is not predetermined.
Models may be used to test ideas, provide descriptions and form hypotheses. Models are tools for scientific thinking and can be included in an inquiry approach to learning.

Table 3. Comparison of Results for Views of models and modelling Science (VOMMS) Instrument for Studies 1, 2, 3, and 4 (n=275)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Total n=275</th>
<th>1 yr 11 n=36</th>
<th>2 yr 8,9,10 n=174</th>
<th>3 univ n=17</th>
<th>4 univ n=48</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Models and modelling in science are important in understanding science.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Representations of ideas or how things work.</td>
<td>85</td>
<td>86</td>
<td>74</td>
<td>88</td>
<td>92</td>
</tr>
<tr>
<td>b) Accurate duplicates of reality.</td>
<td>11</td>
<td>8</td>
<td>26</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>2) Scientific ideas can be explained by:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) One model only, -- any other model would simply be wrong.</td>
<td>7</td>
<td>3</td>
<td>16</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>b) One model, -- but there could be many other models to explain the ideas.</td>
<td>92</td>
<td>92</td>
<td>84</td>
<td>100</td>
<td>92</td>
</tr>
<tr>
<td>3) When scientists use models and modelling in science to investigate a phenomenon, they may:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Use only one model to explain scientific phenomena.</td>
<td>15</td>
<td>17</td>
<td>12</td>
<td>'NA'</td>
<td>'NA'</td>
</tr>
<tr>
<td>b) Use many models to explain scientific phenomena.</td>
<td>85</td>
<td>81</td>
<td>89</td>
<td>'NA'</td>
<td>'NA'</td>
</tr>
<tr>
<td>4) When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Based on the facts that support the model and the theory.</td>
<td>88</td>
<td>83</td>
<td>71</td>
<td>100</td>
<td>96</td>
</tr>
<tr>
<td>b) Influenced by their personal feelings or motives.</td>
<td>11</td>
<td>11</td>
<td>29</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td><strong>Both a and b</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5) The acceptance of a new scientific model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Requires support by a large majority of scientists</td>
<td>23</td>
<td>19</td>
<td>17</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>b) Occurs when it can be used successfully to explain results</td>
<td>70</td>
<td>72</td>
<td>83</td>
<td>59</td>
<td>66</td>
</tr>
<tr>
<td><strong>Both a and b</strong></td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>6) Scientific models are built up over a long period of time through the work of many scientists, in their attempts to understand scientific phenomenon. Because of this scientific models:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Will not change in future years.</td>
<td>7</td>
<td>3</td>
<td>18</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>b) May change in future years.</td>
<td>91</td>
<td>89</td>
<td>82</td>
<td>94</td>
<td>100</td>
</tr>
</tbody>
</table>

*Students chose both a) and b) simultaneously – contradictory to the instructions.*

Note: the percentages provided do not total 100% because several students did not respond. For example, for item 1, 5.5% of students did not respond. (Chittleborough, Treagust, Mamiala, and Mocerino, 2005, p. 201).
MODELS IN THE CURRICULUM

Science curriculum statements encourage the teaching of the nature of science and the way of knowing in science. The Australian National Statements of Learning for Science reflect this in the section of the "Science as a way to know" (Curriculum Corporation, 2006). The Australian National Curriculum includes models as a part of science knowledge—that is described as "facts, concepts, principles, laws, theories and models that have been established by scientists over time." (http://www.australiancurriculum.edu.au/Science/Content-structure). Modelling is presented across all year levels as part of the inquiry process that is commonly included in investigations to provide explanations, predictions and test ideas.

The way models are used in science classrooms does not always make full use of their potential; as Raghaven explains: "Science instruction rarely uses models beyond the purpose of illustration. Students have not been taught how to use models to analyze and solve problems" (Raghavan, 1995 p. 4). Cosgrove and Schaverien (1997) describe the use of models that hinders deep understanding as naïve. This criticism would imply that teachers do not use models to their full potential when teaching science. Yet, models provide scope for visual, verbal and symbolic representations that can be suitable for a variety of learning styles. The research literature provides examples of models being used in integrated and cross curricular approaches. Models are commonly used for descriptive purposes and also for students to create their own models using their imagination (Halpine, 2004).

THE ROLES OF MODELS

Models have been described as thinking tools—but this description is dependent on how teachers and students use the models (White, 1993). Models are commonly used passively for descriptive purposes. The results of research observing a chemistry classroom with seventeen year old students indicated that the majority of students recognised the descriptive nature of models but did not recognise their predictive nature. This is despite their personal experience using chemical models in the chemistry class in tasks on predictive and testing tasks (Treagust, et al., 2004). In addition students did not always understand the role of the model (Treagust, et al., 2003). The way models are used in teaching can reflect the three different roles of models: describing, explaining/reasoning and predicting/testing (see Table 4).

The roles—describe, explain, predict/test—require increasingly higher levels of thinking as described by the Bloom’s taxonomy (reference). Teaching with a model-based approach can provide “opportunities for independent thinking and problem-solving” as described by Zohar and Schwartz (2005, p. 1061) as an essential component of higher order thinking that requires a significant amount of time and effort by the teacher.

WHY USE MODELS?

Models are used to represent abstract concepts, for which there is no other visual or concrete anchor. Students rely on models to build their personal mental model even though they know it may not be accurate or precise.
So for example, for atomic structures, students use the chemical models of elements and compounds to think about, explain and understand chemical concepts.

**Table 4. Various Roles of a Model**

<table>
<thead>
<tr>
<th>Role</th>
<th>Purpose of a Model</th>
<th>Examples in model-based teaching</th>
<th>Type of Reasoning based on (Tytler and Peterson, 2003, p. 459)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To Describe</td>
<td>To represent a particular scientific idea or concept in order to help visualise, and to help understand how something works, moves, feels, and changes.</td>
<td>Students making a model to describe something that is not easily observed - it may be too big or too small to be seen with the naked eye, it may be hidden, or occurs too slowly or too quickly to observe. Examples - a model of the solar system or a model of a cell, a model of internal body parts, the model of a life cycle, a model of a nuclear reactor. Strong emphasis on vocabulary and the function of various components.</td>
<td>“Phenomenon-based reasoning, where explanation and description are not distinguished, and the purpose of experimentation is to ‘look and see’.”(Tytler and Peterson, 2003)</td>
</tr>
<tr>
<td>To Explain/Reason</td>
<td>To represent a particular scientific idea or concept in order to explain a phenomenon, and to describe how something works, and show the connection between concepts/ideas, such as cause and effect.</td>
<td>Make a model to explain a scientific concept - for example making a model of the moon and the earth to explain the changing phases of the moon, or a model of plate tectonics to explain the tectonic features, or a model of how valves impact on blood flow in the heart, and how the diaphragm influence the lungs.</td>
<td>The connection of ideas here-requires phenomenon and relational reasoning. “Relation-based reasoning, where explanation is seen as involving the identification of relations between observable or taken-for granted entities rather than the searching for an underlying cause, and exploratory approaches tend to be confirmatory and uncritical.”(Tytler and Peterson, 2003)</td>
</tr>
<tr>
<td>To Predict/Test</td>
<td>To use a representation of a particular scientific idea or concept to make predictions, test hypotheses, solve problems, and generate causal mechanisms.</td>
<td>Models can be used to make predictions or test ideas such as making models of chemical compounds and using the structure to test their strength or predict their reactivity. The model-based activities include generating and testing hypotheses, and making inferences that require higher order relational mapping of the target and the model.</td>
<td>“Concept-based reasoning, where explanation is cast in terms of conceptual entities that represent an underlying cause or deeper level interpretation, where experimentation is guided by hypotheses, where the role of disconfirming evidence is acknowledged” (Tytler and Peterson, 2003)</td>
</tr>
</tbody>
</table>

In knowledge construction, we usually start with what we know and build on it – in a constructivist manner. But for abstract concepts especially those about very, very small ideas or very, very large ideas – there is no everyday experience to start with so models play a vital part in describing and explaining the idea or concept. Models are used to extend and broaden the conceptual understanding to make learning more meaningful. The categorisation of phenomena-based, relational and conceptual reasoning included in table can assist in highlighting how models can be used to promote various types of reasoning.
TEACHING WITH MODELS APPROACH

Pedagogical approaches that focus on models include model-based reasoning (Stephens, McR Robbie, and Lucas, 1999), the model-observe-reflect-explain thinking frame (MORE) (Tien, Rickey, and Stacy, 1999), the Question, Identify, Gather evidence, Interpret, Model, Predict, Demonstrate (QIGIMP D) approach, (MacIntyre, Stableford, and Choundry, 2002), Models Use in Science Education (MUSE) (National Center for Mathematics and Science, 2002) and Construction, Analysis and Validation - Hestenes’ modelling pedagogy (Hestenes, 1996) and the Interconnected Model of Teacher Professional Growth (IMTPG) (Justi and Van Driel, 2006), Models of Modelling (Justi and Gilbert, 2002). Pedagogical approaches that focus on other processes such as inquiry (Hackling, 2005) or a representational approach with defined pedagogical principles as developed by Hubber, Tytler and Haslam (2010).

The pedagogical principles provide detail to support teacher’s trialling new pedagogical practices. The research literature focuses on the teachers and pre-service teachers as the instruments of change. The pedagogical ideas in these approaches are consistent with a Teaching with Models approach (Hubber, 2009). Six pedagogical aspects are explored as being important for Teaching with Models: Teachers as Learners, Identifying the Scientific Concepts; Target and Then Model, Target and Then Model Again; Setting a Task, Problem or Challenge to Solve; Iterations and Negotiation of Assessment of Models; Characteristics of a Model

1) Teachers As Learners

The teachers must experience the learning using models and therefore need to trial using or creating a model and generating typical responses, as a student. They need to become a learner who is using a model to respond to a challenge in order to appreciate its value. This may mean isolating yourself from your existing knowledge base and relying on the model to make inferences and new observations to generate a response.

Risk Taking

There is an unknown aspect to the lesson when embarking on a pedagogy that includes open ended tasks that encourage students to construct models or generate responses.

Commonly there is no one single correct response. Passing responsibility of learning to the learner – valuing their model or their interpretation or use of it is a necessary transition by the teacher for model focussed pedagogy to be successful.

Start with Where the Student Is At

Consistent with a constructivist approach, current student learning will build on their existing understanding, so it is vital for teachers to determine where the child is at and provide appropriate learning opportunities. Models can be adapted or used at all stages of a lesson or teaching sequence. Models can be used to probe students’ understanding, and to identify their alternative conceptions from feedback about their understanding of the model and the scientific concept being modelled.
2) Identifying the Scientific Concepts

The scientific concept(s) needs to be written in everyday language, with elaborations. Hubber describes a concept in terms of the representations that are used to portray it, "A scientific concept is not simply an idea embedded in curricular documents and textbooks but consists of a set of interlinked representations and practices" (Hubber, 2010, pp. module 1, slide 10). Deconstructing large ideas into smaller ones is a useful task. The excerpts here see Table 5 are taken from the Science Continuum for the topic Living Things Don’t Exist in Isolation. The critical teaching ideas listed on the Science Continuum describe the concepts that are embedded in this topic: The starting point should always be the concepts and then develop model based tasks that will help the learner to develop a deeper and broader understanding.

Table 5. Concepts linked to model based activities

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Model - based activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>“The behaviour of organisms and their interaction with other organisations assists their survival.”</td>
<td>Making a model of a food web to show changes over time. Predicting the impact of an introduced predator, disease etc.</td>
</tr>
<tr>
<td>Organisms have a variety of body parts and structures that assist their survival by making or finding food, finding shelter and reproducing.</td>
<td>Making models of body parts to show adaptive features.</td>
</tr>
<tr>
<td>Organisms of the same type interact with one another and with other organisms in various ways. Some examples are parent/child and feeding relationships, the dependence of many plants on animals for carrying their pollen to other plants or for dispersing their seeds and the dependence of animals on plants for food”</td>
<td>Virtual simulations of populations and the impact of changes. For example Simulations. - virtual (e.g. <a href="http://phet.colorado.edu/en/simulation/natural-selection">http://phet.colorado.edu/en/simulation/natural-selection</a>)</td>
</tr>
</tbody>
</table>


3) Target and Then Model; Then, Target and Then Model Again

Modelling begins with identifying the target. Where possible, when modelling, start with the real thing, noticing its characteristics, patterns, behaviour etc and then design, describe or evaluate a model in terms of the target. This may seem obvious, but remember that models are commonly considered to be the real thing - rather than a representation.

Valuing the observations as scientific data and critically evaluating the model as a means of explaining the data embeds the use of the model in a scientific framework. In electricity for example, it is the light bulb that glows (reality) and the value of the model is in being able to explain or account for this observation in a scientifically sound way.

The particulate nature of matter has become accepted as fact and is often the starting point of many introductory lessons on the states of matter, rather than this model of matter being proposed as a tool to help explain the macroscopic features of solids, liquids and gases.

Because the particle nature of matter is accepted universally, its role as a representation of the real thing and its purpose as an explanatory tool are not always emphasised. It is accepted as a fact rather than a theory - which is represented by various models. Yet it is this role and purpose that provides a way of modelling the process of the development of scientific ideas. When students are taught with a model-based approach they are encouraged
to generate their own models and representations, interpret ready made models, and answer the questions:

- Which observed characteristics of the phenomena does the model explain, and which doesn’t it explain?
- Can you use the model to make predictions about changes in the observed characteristics of the phenomena?

When the target is unfamiliar or unknown the model can assume the role of the target and the real target becoming categorised as suspicious, or in denial as described by Al-Balushi (2011).

Multiple models can provide a variety of perspectives and appearances and students recognise that multiple models can be useful in explaining ideas in different ways (Chittleborough, et al., 2005).

Experiences with multiple models should enhance the constructing of personal mental models where the learner draws on attributes from multiple models. Using multiple models can reinforce their role of the model and highlight the variety of characteristics. In electricity for example, a role-play, a virtual simulation, a circuit diagram, can be mapped to the students experience with setting up a real circuit.

4) Characteristics of a Model

The strengths and limitations of a model in relation to the real thing needs to be discussed and assessed —thereby focuses on the mapping. Criteria can be useful to guide an evaluation of a model. The acronym MAP describes some criteria of models: the Mode of representation (M), the Accuracy of the model (A), the Purpose of the model (P) (Chittleborough and Treagust, 2009), see Figure 2.

5) Setting a Task, Problem or Challenge to Solve

The setting of a challenge or problem provides incentive and motivation for learning. Even when models are used for descriptive purposes, mapping between the target and model is required. Setting challenges so that they are appropriate for the student and for the student’s conceptual development takes professional consideration.

The tasks need to be positioned in the zone of proximal development (ZPD) for the learner, as described by Vygotsky (Crawford and Cullin, 2004; Tytler and Hubber, 2010).

Ideally, a challenge or problem should be open ended with no single correct solution. It should require higher order thinking.

For example making a model to compare the phases of the moon in northern hemisphere and southern hemisphere takes students away from a textbook answer. The textbook would however, provide useful starting information.

The development of modelling and science skills is gradual with tasks designed with developing autonomy. Similar to the guided inquiry approach described by Hackling (2005), the teacher can provide support as necessary to scaffold the development of modelling skills.
Table 4 presents an increasing degree of thinking and reasoning required as the role of the model changes from descriptive to explanatory and onto predictive and testing.

6) Iterations and Negotiation of Assessment of Models

Modelling is an active process requiring mapping and comparison in an iterative approach, that can be done individually or in groups. Feedback from the model and negotiation of understanding among peers should assist the evaluation of models (Justi and Van Driel, 2005). The model in itself is not evaluated, rather its effectiveness at representing the target. The target/model focus directs the pedagogical approach to cover all three aspects of the model - the subject matter, the process of science and the nature of science.

PEDIAGOGICAL CONTENT KNOWLEDGE OF MODELS AND MODELLING IN SCIENCE

Models and modelling is a good pedagogical focus for teaching science because it addresses all aspects of science learning - the knowledge, the nature of science and the process of science, and challenges the criticism of science teaching being recipe driven or fact orientated or simplified to activity sciences, and hands-on science. Models and modelling promotes active learning that has a student centred approach with collaborative hands-on activities. In addition, models and modelling can promote metacognition by the student reflecting on the role and purpose of the model in their own learning and mental model development about the concept. (Chittleborough, et al., 2005).

The pedagogical power of model-based approach is in its authenticity reflecting a scientific way of working. Pivotal is how the teacher scaffolds the mostly student-centred learning.

All the research indicates that the model does not do the teaching and learning, rather it is how the model is used that can make it an effective tool for teaching and learning.

These uses of models to describe, explain, make predictions and test ideas about the scientific concepts, relate the use of models to the way scientists work, and reflects on the nature of science and the development of scientific ideas.

A study that used a model-based teaching approach with Year 11 chemistry students in a Western Australian chemistry class resulted in the students' verbal and manipulative skills positively impacting on their understandings of the chemical concepts (Treakust, Chittleborough and Mamiila, 2003). Initially these students' abilities to talk about the models and the scientific concepts meaningfully were lacking and their vocabulary was limited, however, this improved over the period of the study. Providing students with time to work collaboratively with the models was an important part of learning how to use the model and to appreciate their role. But probably even more important was the challenge that the teacher gave students - problem solving tasks that were not immediately easy to solve - that challenged the students, increased the competition and forced the students use the models to help them think and work out a solution. Forcing students to make a prediction or test an idea requires them to use the model to make a judgment.
Constraints to adopting a model based approach include – the extra time needed for negotiation and discussion, the willingness to take risks with an unfamiliar pedagogical approach in the classroom, and giving students more responsibility for their own learning often with an unknown outcome. These constraints are balanced against the demands of curriculum and assessment (Coll, France, and Taylor, 2005).

DIGITAL TEACHING MODELS

New technology brings new types of models. The explosion in information computer technologies has meant that the quality, accuracy, detail and capabilities of visual representations including animations and simulations are constantly improving to higher standards, along with lower costs and increased availability. The use of visual representations in science education is commonplace and expected, especially among learners who have grown up in a visual-learning domain. With new technologies the availability and variety of models has increased dramatically.

Gilbert (2005) has concluded that “there is a steadily growing body of research that suggests that student achievement in science is generally supported by direct access to multimedia forms of representation” (p. 14). Models can provide opportunities for authentic, active student-centred learning (Roth, 1995), such as thinking, interpretation, deductions and deeper understanding. Teachers can take advantage of the models and scaffold these learning opportunities.

Despite the new types of models the pedagogical issues remain the same- the model does not do the teaching and learning, rather it is how the model is used that can make it an effective tool for teaching and learning. The increase in the availability of the excellent visual representations may be the trigger that makes us examine more closely how models are used effectively in teaching and learning.

CONCLUSION

Teaching with models can promote science by having teachers and students use models not only to explain scientific ideas but also during inquiry activities, at the same time modelling typical scientific behaviour. The authenticity of a model based approach to teaching science motivates teachers and students and creates learning opportunities. Immersing teachers in model based learning to raise awareness of the excitement, the risks, the cooperative work and the fun that is part of doing science.

REFERENCES


