

Why Models are Advantageous to Learning Science

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ABSTRACT

Models are used routinely in science classes to help explain scientific concepts; however, students are often unaware of the role, limitations and purpose of the particular model being used. This study investigated Years 8-11 students' views on models in science and used these results to propose a framework to show how models are involved in learning. The results show that students' understanding of the role of models in learning science improved in later grades and that many students were able to distinguish the purpose of scientific models from teaching models. The results are used to identify the criteria students use to classify models and to support pedagogical approaches of using models in teaching science.

KEYWORDS: Scientific models, Teaching models, Student learning, Student understanding

Introduction

Models provide representations of scientific concepts that can make the ideas more understandable to learners (Huddle, White and Rogers, 2000). Modeling requires the user to make links between the model and the reality that is being modelled. This activity includes the assessment of the model itself and an evaluation of how the model maps to the scientific concepts represented. Previous research has indicated that students' appreciation of models is limited and naïve (Grosslight, Unger, Jay and Smith, 1991). However, to understand why models are advantageous to learning science, it is necessary to look at how models are used and how students perceive the models. Using this background, the role that models play in contributing to learning can be investigated.

Background

Students' ideas of models originate from their everyday experiences that are usually associated with scale models and computer simulations. This study focused on scientific models; however, students do not always differentiate between scientific models, teaching models and models in general, and all definitions of models are included in our discussion. Models are often seen as teaching tools that enhance the visualization of abstract concepts.

Students' and experts' understanding of models

The significant difference between students' understanding of models and that of experts has highlighted the inadequate

understanding that some students have of the model concept. Inadequacies include the student focusing on the surface features of the model, students being unable to transfer from one model to another easily, and not being able to identify the features of a model (Kozma and Russell, 1997). Research has shown that students have a naïve understanding of the role of models in science (Grosslight, Unger, Jay, and Smith, 1991). This result is not surprising considering that even though models are used extensively, across diverse fields, they are usually used without elaboration of their role, their symbolic nature, their limitations and their strengths. The passive use of models leaves the student with the perception of models as descriptors, whereas the active use of models can develop the perception of models as interpretive and predictive tools.

There are two aspects of models that can be considered: 1) How the model is used as an explanatory tool of scientific concepts, and 2) Appreciation of the role, purpose and limitations of a model. The use of models includes being a descriptive or explanatory tool, using the model to test ideas, make predictions, and formulate hypotheses. Research into the use of chemical models has shown that the descriptive nature of models was better understood by students than the predictive role of models (Treagust, Chittleborough and Mamiala, 2004). Models can be used to encourage students to analyse and evaluate scientific ideas. However, using a model may not be enough to ensure that the students have an appreciation of their role, purpose and limitations of models. When using model-based reasoning, students' need to have a good knowledge of the model itself, and also be familiar with the connections between the model and the target.

The role of models

For students to understand the role, purpose and limitations of models, it is necessary for them to have a notion of the role of models. Models are useful tools in learning science which

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can be used to improve explanations, generate discussion, make predictions, provide visual representations of abstract concepts and generate mental models (Treagust, Chittleborough and Mamiala, 2003). Consequently, models can play a significant epistemological and pedagogical role by providing learning opportunities. To improve these aspects, Gilbert (1997) has recommended a more authentic treatment of the process of science with teachers being educated to use and present models in a more scientific way. As students use models discerningly, appreciating their role, purpose and limitations, links are formed between the model and the target, and each learner constructs a personal mental model for the concept.

Classifying models

Classification schemes of models are useful because they provide students with a framework with which to highlight and understand the role, purpose and limitations of particular models. These schemes can lead students to develop ways of thinking about new models, ideas and theories. The common method of classifying models is according to their type, form and method of use (Gilbert and Osborne, 1980; Grosslight, Unger, Jay and Smith, 1991). Gilbert (2004) described four different categories of models: a consensus model—an accepted model, tested by scientists and socially agreed upon; a teaching model—a model used to help explain something; an expressed model—the personal expression of the students understanding of the phenomena in speech, actions or writing; and a mental model—the personal internal understanding of the phenomena.

An awareness of the attributes of a model is important in appreciating the role, purpose and limitations of a model: firstly by enabling learners to recognise the strengths and limitations of the particular model, secondly as a method of classifying the model, and thirdly in recognising the level of representation at which the model is presented. Without realising, we classify and sort everything we encounter using our own personal criteria and positioning it in our mental framework. The use of classification keys, categorising criteria, and sorting methods provides students with methods of sorting information that may extend their current framework or require a new framework to be adopted.

Mental models and models

Mental models can represent discourse about real, hypothetical, or imaginary situations (Johnson-Laird, 2001). It is a window into the learners' understanding and can be used by the learner to give explanations, make predictions and provide reasoning. The personalised mental model of a learner is described by Norman, (1983) as hazy, incomplete and messy, by Brewer (1999) as ambiguous.

Models help learners to generate personal mental models. The development of learners' mental models occurs as learners use models, make predictions, get feedback and modify their understanding (mental model) accordingly. This reflec-

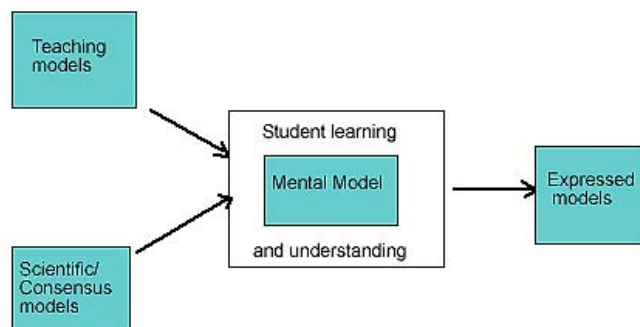


Figure 1. A theoretical framework of models in the learning process.

tive and recursive learning style is dependent on the learner being challenged to make predictions and applications, but can be rewarded with a more meaningful and deeper understanding. The framework presented in Figure 1 from Chittleborough, Treagust, Mamiala and Mocerino (2005) is based on the research literature and diagrammatically presents the role of the four types of models in learning.

The aim of the study

The aim of the study is to understand why models are valuable tools in learning by investigating: 1) How do students' perceive models in respect of their learning science?, and 2) What are the criteria that students use to classify models? The first research question provides the foundation for the second research question. These data are reported in more detail in Chittleborough et al. (2005).

Method

This study surveyed students about their general views on models to gain a more accurate assessment of their perceptions. The instrument My Views of Models in Science (VOMMS) (see Appendix) was used to understand students' ideas about models. Responses were obtained from 210 students from three different schools and across four Year levels, 8, 9, 10 and 11. All schools were coeducational, with two being state high schools and one being a private college. The Year 8, 9 and 10 students were studying general science and the Year 11 students had chosen to study chemistry. The students sampled had no specific teaching about models; however, the chemistry students had used chemical models in their classes.

The six items in the VOMMS instrument evolved from Aikenhead and Ryan's (1992) Views of Science-Technology-Society item bank of questions. Each item required students to choose between two alternative statements about scientific models, thus forcing them to take a definitive stance in response to the question. For example, given the statement in item 1, 'Models and modelling in science are important in understanding science', students were asked to choose whether models are representations of ideas or how things work, or

are accurate duplicates of reality. The Year 11 students were also required to provide a reason for their choice. Statistical differences using SPSS were investigated with respect to gender, age and school. ANOVA tests were performed on all items in the survey to identify any differences between different Year levels; t-tests were used to identify any gender differences. The VOMMS instrument has a Cronbach alpha reliability of 0.83 indicating that the results of the items are consistent throughout the instrument.

Results and Discussion

Students' perceptions of the role of models in science

In response to Research Question 1 — How do students' perceive models in respect of their learning science? — the students' perceptions of models were measured based on the percentage responses to the VOMMS instrument. The responses showed that a majority of students (>70%) view models as a representation of ideas or how things work (item 1); that there could be many other models to explain ideas (item 2); that models are used to explain scientific phenomena (item 3); that a model is based on the facts that support the theory (item 4); that a model is accepted when it can be used successfully to explain results (item 5); and that a model may change in future years (item 6).

An independent t-test performed on the six items found that only item 5 was statistically significantly different ($p < 0.05$) in respect of gender. In that item, the female students responded more positively, demonstrating a more scientifically sophisticated view of models. An ANOVA analysis on the results for each item with respect to Year level showed statistically significant differences ($p < 0.05$) between the Year levels for items 1 and 2. For both items there was an increase in the number of students choosing the more scientifically valid response with age.

Three distinguishable conceptions about models

There are three distinguishable conceptions about models identified by the instrument, with item 1 of the instrument examining the idea of models as representations, item 2 and 3 looking at the multiplicity of models and items 4, 5 and item 6 probing the dynamic nature of models.

Models as representations

There were significant differences across the year groups with 23%, 34% and 25% of Year 8, 9 and 10 general science students, respectively, and only 9% of the Year 11 students described a model as an accurate duplicate of reality. This result compares to those reported by Grosslight et al. (1991) where even higher percentages of students (about 50%) believed that 'the model should be exact, smaller or proportional' (p. 810). The difference between the age groups is significant and provides clear evidence that older and more experienced students have a better understanding of the nature of models.

Indeed, many scientific models are not exact and with more abstract concepts imprecise models are used because reality is too complex, even impossible, to duplicate. There is a dilemma for some students in accepting the lack of precision of some models. The reasons given to support the answer in item 1 that models are representations include 'helps us to explore things too small to see', "How atoms look is a theory, no one has actually seen them", "Science is too complicated, it can't be an accurate duplicate of reality", and "They are how we want to think things behave or look like. However, they aren't accurate as there are many exceptions". "Although I understand that the models aren't the real thing, it does make it easier to see how a molecule may work" and "they only help us to gain an idea of how something should look and how it behaves etc". These comments reflect the complexity of the model concept and the subtle differences in students' interpretations. In contrast, reasons given to support the alternative response that models are accurate duplicates of reality include: "proven and tested that it is accurate", "because that is how they are represented in the chemistry text book" and "atlas". The issue of reality arises here, with most students understanding that the model is not real but is a representation.

The multiplicity of models

Items 2 and 3 examined the coexistence of multiple models, revealing that almost 90% of students agreed that many models can be used to explain scientific phenomena. When considering the importance of using more than one model, students supported their choice by saying, "There can be several models that work because no one actually knows what is correct"; "to see things from different perspectives"; "different models of the same thing may be used to emphasise and show in detail certain aspects" and "phenomena are things we try to understand and it may take various models to make clear the phenomena and how it works". Despite this very high response there was still a significant difference between the Year groups with 31% of Year 8 students agreeing that 'one model only' is preferable. This result supports the assertion that older and more experienced students have a better understanding of the roles of models and the diversity of model types as suggested in the previous section.

The dynamic nature of models

Items 4, 5 and 6 dealt with the changing nature of models, with 73% of students believing that a model is accepted on the facts that support it and the theory; 86% agreed that a model is accepted when it can explain results and 83% believed that scientific models will change in the future. The differences between the groups are quite marked in Item 4 with 40% of Year 8 students believing that scientists are 'influenced by their personal feelings or motives' compared with 23% of Year 11 students who hold this view. Similarly with item 5, 29% of Year 8 students believe 'scientific models will not change in future years' whereas only 17% of Year 11 students support

this idea. The consistency in the differences between year groups for items 4, 5 and 6 supports the assertion that the students are gaining a better understanding of the role of models as they learn more about science. The reasons given to support the concept of the dynamic nature of models included “facts may change due to technology”, “they have been proven wrong in the past, so what we are learning now might all be non-existent or wrong” and “As we generate a greater understanding of subjects we will be better able to create increasingly ‘correct’ models”. These responses, which referred to scientific models with respect to their role in the scientific world and the scientific process and link the scientific model to the broader perspective of scientific changes, provide evidence that a few students are developing a dynamic perspective of science. This epistemological perspective is not usually taught directly in class but more often indirectly through example. The responses of the Year 11 students given as justification for their choice provided evidence of a wide range of understandings.

A sophisticated argument provided by three students for Item 5 justified that the acceptance of a new model goes beyond the valid belief of the model needing to successfully explain results. One student explained that ‘if a new scientific model is not accepted by the majority of scientists, it won’t be used — even if it does successfully explain results’. Another student responded ‘without support, then you can’t succeed, other scientists have to prove your model is valid’. A developing/mixed epistemology is commonly exhibited in the comments such as ‘It has already been proven that scientific models will change as understanding increases and technology develops, models may be incorrect or not up to date as they should be’. The above comments illustrated the links between models and the students’ understanding of the process of science.

The results of this study are encouraging because the majority of students had a scientifically acceptable understanding of the model concept and the level of understanding improved with increasing year levels in this cross-age study. However, the study also identified some students’ weaknesses and alternative conceptions that have been used as a basis for identifying what students need to know about models. Alternative conceptions include: a model being an exact copy; there being only one possible model for a particular phenomenon which is unchangeable; and the value of a model being determined by scientists’ opinions.

Criteria that students use to classify models

In response to Question 2: What are the criteria that students use to classify models?, the three conceptions of models identified by the instrument have been used to develop a typology of models targeting the common alternative conceptions that students have shown in this area: Models as representations — refers to the purpose of a model and the accuracy of a model; The multiplicity of models — refers to the mode of representation; The dynamic nature of models — refers to the

permanency of models. A typology based on these three conceptions highlights the attributes of particular models and should address the alternative conceptions by investigating four characteristics:

1. The Mode of representation refers to the physical nature of the representation e.g., visual, concrete, symbolic, verbal, 2 or 3 dimensional, static or dynamic, digital, responsive, interactive.
2. How Accurate is the model? Is the representation an exact replica or scale model of the target? Is it imprecise or impressionistic?
3. What is the Purpose of the model? Is it a teaching model, an explanatory model, a predictive model, a mental model, a theoretical model, an analogical model, a scale model, or a simulation? More than one response may be correct.
4. The Permanency of the model. Is this representation accepted as fact? Is it just an idea?

These attributes (Mode, Accuracy, Purpose and Permanency — abbreviated with the letters MAPP) can be used to classify models in a descriptive way and may help students develop their own ontological framework for models. It is mostly assumed that students generate their own personal typology of which they may or may not be cognisant. However by presenting the significant criteria, students are assisted and directed in this process.

A theoretical framework for learning with models

The classification criteria (MAPP) developed from the results of this study can be used to help identify the attributes of models, in all four types of models considered, and is incorporated into the original theoretical framework of models that was developed from the literature (Figure 1), to produce Figure 2. This theoretical framework (Figure 2) of models in the learning process provides an overview of how and why models are advantageous to learning.

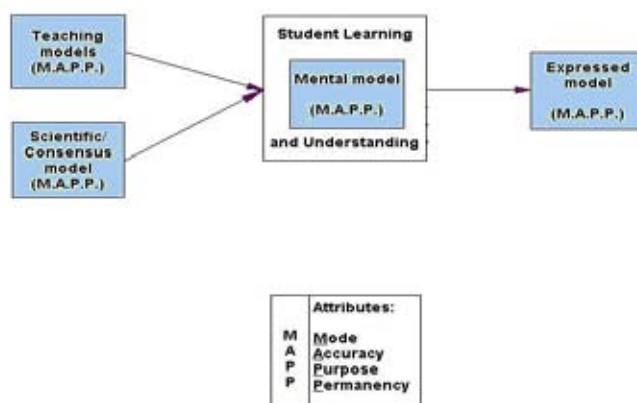


Figure 2. A theoretical framework of models in the learning process including the model attributes.

The basic input and output classification explains how the four different model categories (Gilbert and Boulter, 1995) relate to the learning process while ontological and epistemological aspects of students' understanding can also be layered onto this scheme. Through teaching we endeavour to change, develop or modify students' thinking and understanding to be more scientifically acceptable. The analysis here focuses on the students' understanding of the model concept only, without considering the actual scientific concepts and knowledge which the models are being used to explain.

The focus of the framework is indeed the learning process and the development of the learners' mental model. Learning can be described as the construction of mental models. Metacognition is a reflection of a learners personal knowledge or thinking (Rickey and Stacy, 2000). Each individual has to evaluate and integrate new information into his or her existing meta-cognitive framework. There is extant literature on this process highlighting the difficulties and accounting for the alternative conceptions that arise. The mental model and the scientific model can contradict each other when they are grounded in different general frameworks (Duit and Glynn, 1996). Tiberghin (1994) investigated how students are modelers themselves by constructing their own mental models to validate their own knowledge structure. Bodner and Domin (2000) investigated the use of representations in problem solving in which knowledge schema were activated and the success of the problem solving was dependent on the student constructing a representation to establish a context for understanding the problem on which other representations could be built. This finding demonstrates the relationships between the knowledge framework and representations and the accommodation and assimilation of new information. Meaningful learning via the internal construction process not via the direct transmission process requires learning by doing, and by construction and criticism rather than by listening and is reflected in an integrated knowledge schema.

The expressed model is the personal expression of the students' understanding of the phenomena, the product of the students' knowledge construction, which can provide some indication of their mental model. The simplified framework is not exclusive — there are many factors influencing the learning process, nevertheless, this analysis has focussed on the role of models in learning.

Other research has indicated that teachers recognise the importance of models in learning (Savec, Vrtacnik, Gilbert and Peklaj, 2006; Van Driel and Verloop, 2002). Students' representational competence is a necessary skill that is developed through modelling and practice (Kozma and Russell, 2005) and teachers can play a significant role. An intentional pedagogical approach using the MAPP framework could enhance this skill.

The VOMMS instrument has provided evidence that many students have a good understanding of the role of models in science with respect to the representational nature of models, the changing nature of models and the multiplicity of models.

A cross-age analysis of student responses to the data showed that all items in the instrument support the assertion that these students gained a better understanding of the role of models as they learned more about science. Some Year 11 students provided evidence of having developed a scientific epistemology.

The term model and its use in science are wide and varied. The recognition of different model attributes including mode, accuracy, purpose and permanency may improve students' ontological understanding of models particularly the category, type, role and position of models in the process of science. This recognition has the potential to improve students' ontological perspective of models.

The theoretical framework for models and learning provides a means of understanding how models are involved in the learning process. Since all learning leads to mental models it is valuable to understand the relationship between model categories and learning. This improved understanding has the potential to improve learners' epistemological perspective.

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APPENDIX

The instrument My Views of Models in Science used in the study.

Statement

- 1) Models and modelling in science are important in understanding science. Models are:
 - a) Representations of ideas or how things work.
 - b) Accurate duplicates of reality.
- 2) Scientific ideas can be explained by:
 - a) One model only, — any other model would simply be wrong.
 - b) One model, — but there could be many other models to explain the ideas.
- 3) When scientists use models and modelling in science to investigate a phenomenon, they may:
 - a) Use only one model to explain scientific phenomena.
 - b) Use many models to explain scientific phenomena.
- 4) When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:
 - a) Based on the facts that support the model and the theory.
 - b) Influenced by their personal feelings or motives.
- 5) The acceptance of a new scientific model:
 - a) Requires support by a large majority of scientists.
 - b) Occurs when it can be used successfully to explain results.
- 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:
 - a) Will not change in future years.
 - b) May change in future years.