Students' understanding of the descriptive and predictive nature of teaching models in organic chemistry

by

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Abstract

The purpose of the study was to investigate secondary students' understanding of the descriptive and predictive nature of teaching models used in representing compounds in introductory organic chemistry. Of interest were the relationships between teaching models, scientific models, and students' mental models and expressed models. The results from classroom observations, interviews with students, and completion of student questionnaires showed that the majority of students involved in this study had a sound understanding of the descriptive nature of teaching models but their understanding of the predictive nature of those models was limited, despite their experience in using a variety of representations in chemistry class. The data suggest that teaching models can play a pivotal role in initiating students' development of scientific models, mental models, and expressed models. In light of these results, it is suggested that teaching models be used to predict, test and evaluate conceptions similar to the way that scientists use scientific models so that students appreciate the similarities of teaching models and scientific models.

Key Words: mental models, organic chemistry, scientific models, teaching models, upper secondary science.

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Introduction

Chemists and chemistry teachers are able to use different representations of molecular structures such as the ball and stick model or space-filling models to explain features and functions of the molecule under investigation. However, typically secondary students do not perceive these different representations in the same way as their teachers because each representation is seen as something new to learn rather than to explain what is to be learned. The chemical representations which include chemical equations, symbols, diagrams, illustrations and models, serve as tools to help the learner construct a mental model. These tools are used in conjunction with the conceptual model that the learner uses for understanding the new scientific concept (Duit & Glynn, 1996).

A model can be defined as a representation of an idea, an object, and a processor, and as a system in which a target is matched with an analog (Gilbert & Boulter, 1998). Building on the work of Gilbert, Boulter, and Rutherford (1998), examples of models include *a scientific or consensus model* - the accepted model of a scientific theory that has been subjected to testing by scientists and which has been socially agreed by some of them as having merit; a *teaching model* - a specially constructed model used by teachers to aid the understanding of a scientific or consensus model;; *a mental or conceptual model* – a personal private representation of the target which emerges from experiences with more than one example of an event or object; and *an expressed model* - that version of a mental model which is expressed by an individual through action, speech or writing. Each type of model has a unique role: for example, the scientific model may not be easy to understand, so a teaching model is devised to explain the scientific principles of the scientific/consensus model (Giordan, 1991). Since teaching models are designed to be appropriate to the learners' level of understanding they are often more simplistic than the scientific model but they still play a similar role and have the same characteristics as scientific models.

Two primary functions of models are their descriptive and predictive roles, the former being more obvious than the latter. A model's descriptive role includes showing what an entity may look like and how it behaves, whereas a model's predictive role includes using the model to make and test predictions, solve intellectual problems and test ideas. The objective of this research was to investigate students' use of models, in particular that the use of multiple teaching models of organic chemistry compounds might lead to greater application and conceptual understanding of the scientific theory on which the models are grounded.

The different representations of molecules – two-dimensional drawings, ball and stick models, space-filling models and computer simulations – are forms of teaching models that can also be considered to be scientific models (Gilbert et al., 1998). When teaching models are used in high school chemistry, they can be used in a constructivist manner to challenge students' internal knowledge schemes (Yager, 1991). The importance of student discourse when using models constructively emphasises the social aspect of learning as reported by Boulter (2000). The use of teaching models can encourage discussion and the articulation of explanations that encourages students to evaluate and assess the logic of their thinking (Raghavan &

Glaser, 1995). Indeed, model-based reasoning is a highly desirable skill, but it does require extensive instruction and practice within the culture of the classroom (Stephens, McRobbie, & Lucas, 1999). In this manner, model-based teaching and learning is consistent with personal and social constructivist theories of learning where the focus is on the learner with all learning dependent on language and communication (Cosgrove & Schaverien, 1997; Gergen, 1995; Yager, 1991).

Teaching models include a variety of representations that may or may not accurately portray all aspects of a phenomenon (Treagust, Chittleborough, & Mamiala, 2002). This is commonplace in science, yet many students have little understanding of the value or role of both teaching and scientific models in school science and in the scientific world (Grosslight, Unger, Jay, & Smith, 1991; Harrison & Treagust, 1996; Linn, Songer, & Lewis, 1991; Smit & Finegold, 1995). It is likely that students' visualisation of various types of models fosters conceptual development and conceptual changes by inducing shifts in learners' mental models (Norman, 1983). In terms of their ability to recognise a model as an entity or a mental tool, research has shown that many secondary students view models only as copies of the scientific phenomena and that their understanding of the role of models is both naïve and simplistic (Grosslight et al., 1991). According to Ingham and Gilbert (1991) even tertiary-level chemistry students have limited experience with models and only a small percentage of these students have an abstract understanding of models in chemistry. In a cross age study, Coll and Treagust (2001) describe similar outcomes when undergraduate and postgraduate students tended to use simple teaching models learned in high school to explain chemical bonding. Because no single model provides the total evidence for the structure and function of an organic molecule, each student's understanding is reliant on realising the limitations and strengths of each teaching model (Hardwicke, 1995). Even teachers' levels of understanding of models in science have been described as limited because they have a simplified understanding resulting from a variety of cognitions about models and modelling in science (Van Driel & Verloop, 1999). Gilbert (1997) recommends that teachers have to be educated to use teaching models in a more scientific manner and they in turn need to teach this understanding to their students.

Nevertheless, modelling is commonly used in the chemistry laboratory where the chemistry teachers' understanding of models and their role in the development of scientific ideas is part of their personal philosophy of science and is central to their pedagogy (Selley, 1981). Duit and Glynn (1996) remind us that although the modelling process leads to mental models, guided modelling is required to ensure attainment of the scientific or consensus model. Instructors are instrumental in teaching and challenging learners and the way that teaching models are used appears to be a significant influence on their effectiveness and their impact on students' epistemologies.

The purpose of the study was to investigate secondary students' understanding of the descriptive and predictive nature of teaching models used in representing compounds in introductory organic chemistry.

Design and Procedures

Sample

The study was conducted with two classes of Year 11 students (16-17 years of age, n=36) from a private co-educational high school in Perth, Western Australia. The same teacher who had recently participated in a professional development program taught both classes. The professional development program on integrating the use of teaching models and analogies into science lessons (Treagust, Harrison, & Venville, 1998) introduced the concept of a target and analog and recommended Focus-Action-Reflection as a suitable teaching strategy. The purpose of this teaching approach was to make overt the relationship of features between the target (an organic molecule) and the analog (one of the four types of teaching models described below).

Teaching Context

The research took place in the teacher's two chemistry classes over a period of three-weeks, during the introductory organic chemistry unit that included topics on the structures and properties of alkanes, alkenes, alkynes, cyclo-alkanes, nomenclature, isomerism, and substitution, addition and combustion reactions. The four types of teaching models used to depict the organic molecules were structural formulae, ball and stick models, a computer-modelling program - *The Chemistry Set (1995)*, and space-filling models. Primarily, the students used the ball and stick models while working in pairs, but they also saw, but did not use, some space-filling models and had access to *The Chemistry Set,* a computer program, in the library.

The teacher did not discuss the role of models in the process of science, but did modify his teaching style to include the four teaching models. He introduced the ball and stick models before any structural formula had been used, and continued with this sequence throughout the organic chemistry unit. The class usually experienced a more teacher-centred and textbook-oriented class, so the group-work and deductive activities were new to the students. The general pattern of each lesson observed was for the teacher to provide some background information on the topic, after which the students were given a task to build models of particular compounds. Each task was presented as a challenge with the students keen to draw the structural formula representation of the chemical model on the whiteboard prior to their responses being discussed by the class as a whole.

The computer software, *The Chemistry Set,* allowed students to look at a variety of compounds in a ball and stick image and it was possible to remove the balls and just look at the sticks and then remove the sticks and just observe the balls moving. This feature was beneficial in giving an image of the region of influence of the electrons and to emphasise that the balls and sticks are just tools to help visualise the molecule. However, only translational movement was possible, either by the computer program moving the compound in a random motion around the screen or manually by the user directing and controlling the motion with the computer mouse.

Data Sources

Both classes experienced identical teaching programs so for analysis, the data were combined and treated as a single sample. Quantitative and qualitative data collected in this study served as a form of methodological triangulation (Cohen & Manion, 1994 p.236) in order to improve the validity and quality of data (Anderson, 1997; Burns, 1997; Mathison, 1988). The data collected included classroom observations, audio-taping of the students' interactions during group work, interviews with students, video-taping a practical test in which students used ball and stick models and the administering of two instruments, - *Molecular Representations* and *My Views of Models and Modelling in Science* (*VOMMS)* at the end of the course of study.

Quantitative Data Sources

Student responses to the instruments provided data on students' understanding of teaching models and modelling in science. The first instrument, Molecular Representations, required students to respond on a 5-point Likert scale from strongly disagree to strongly agree to questions on the purpose of each of the four teaching models they had encountered during the previous three weeks. Such questions were to consider the purpose of the ball and stick model, for example, as showing what the molecule looked like, or showing how the molecule behaved, or showing the shape and structure of the molecule (see Table 1). The instrument compared four scales on molecular representations, namely, structural formula, ball and stick, computer and spatial models. Each scale contained 11 items. The items were developed with consideration of previous studies (Barnea, 2000; Copolo & Hounshell, 1995; Gabel & Sherwood, 1980; Gilbert, 1991; Grosslight et al., 1991) incorporating model typologies and attributes of models (Gilbert & Boulter, 1998; Harrison & Treagust, 2000; Van Driel & Verloop, 1999). The validity of the items was based on their scrutiny by the authors attending to the purpose of the model and trialling with a small sample of students. In response to this scrutiny and trial, vocabulary and layout were improved and the use of diagrams was included. The Cronbach alpha values showing internal consistency of the scales of the instrument given to this group of students ranged from 0.69 to 0.85 indicating that the reliability of each scale was acceptable. Although normally reliability measures above 0.8 are preferred, here interviews, student conversation and video data have contributed to clarify the students' understanding of items in the instrument, *Molecular Representations* and in this way have supported the reliability values and therefore the validity of the instrument (Gall, Borg, & Gall, 1996).

The second instrument, *My Views of Models and Modelling in Science*, required students to choose between two alternative statements about scientific models and then explain their choice. These items evolved from Aikenhead and Ryan's (1992) item bank of questions on Views of Science-Technology-Society (VOSTS) and were designed to investigate students' general understanding of models, with the items focussing on the role of models in science. For example, given the statement, "Models and modelling in science are important in understanding science", students were asked to choose whether models are representations of ideas of how things work, or accurate duplicates of reality (see Table 2). In addition, an open response sought evidence to justify the students' choice. The validity of the evolved items was established through peer review. The naturalistic methodology used by Aikenhead (1992) in the original instruments was based on students' perspectives, not on how "science educators supposed students might reasonably respond" (p. 488). The Cronbach alpha of 0.87 for this instrument with this group of students indicated a high reliability within the scale of items dealing with students' views of models and modelling in science.

Qualitative Data Sources

The practical examination was videotaped and observed learning strategies coded with an identifying number corresponding to the time elapsed on the video. The examination results were obtained. However, without pre-testing and without the results of a control class they were of little value for inferring how much the model-based learning had been responsible for student achievement. Despite this, the video provided insight into the way that students used the ball and stick models to answer the test questions.

Two authors took on the role of participant observers in the classroom during the lessons (Merriam, 1998) in order to document the interaction between the students and observe how they made use of models in understanding the naming and identification of structures and properties of organic compounds. During all student activities, pairs of students working together were randomly selected and audio-taped. The interview questions were usually in response to the set task. For example: So what if we decide to change this one (methyl group) and connect it here, Does it change anything?; Which carbon does it come off?; How do you name it?; Why do you say the right one (carbon atom) is the same as the middle one?; If you break that bond then what will you form?

Data Analysis Procedures

Data were analysed and interpreted on a continuous basis by the researchers. A four-digit identification number identified students' responses from the quantitative data. The Statistical Package for Social Scientists (SPSS) (Coakes & Steed, 1996) was used to analyse the quantitative data. The audiotapes of students working together in pairs and responses by the interviewees during the interviews were transcribed. The video of the practical test was also transcribed. Data from audio and video transcriptions were reported with an identification number corresponding to the line number in the transcription record. The participant researchers reviewed audiotapes and video descriptions, to check whether or not the information collected in the observation schedule were accurate. The qualitative data were coded in terms of relevant aspects of students' understanding and activity (Silverman, 2000). There were fourteen coding categories. Examples of the coding for audio data included: Students used the models to work out the name for the compound they had made; the use of models in the teaching of organic chemistry motivated the students' interest; and students easily swapped from the three-dimensional model to two-dimensional model. Examples of the coding for video data include: Students made different isomers and then compared them; and students used the model's physical characteristics to help them explain the chemical characteristics. Both participant researchers crosschecked this coding, after which the third author rechecked the analysis (Merriam, 1998).

After the analysis of the quantitative data, and the examining of the qualitative data, themes were identified as they emerged from the data. Further discussion between the authors and the teacher established the validity of these themes. The results also were discussed for confirmation of the deductive reasoning that had occurred.

Results and Discussion

The analysis of the data is structured around two themes concerning students' understanding of teaching models. The first theme relates to the descriptive nature of teaching models; the second theme relates to the predictive nature of teaching models.

Theme 1: Students were able to describe the features and purposes of different teaching models for simple organic molecules.

Analysis of quantitative data

The analysis of the data from the *Molecular Representations* instrument indicated that the majority of students understood the purpose of each of the four teaching models that they had encountered during their organic chemistry unit (see

Table 1). This understanding refers to an accurate depiction of the attributes of the model being surveyed, including its limitations and strengths. A high percentage of students strongly agreed or agreed that the structural formula representations showed the existence of chemical bonds (83%, item 4), and similarly approximately two thirds of students claimed that the structural formulae helped generate a picture in their mind (70%, item 6). The students used the ball and stick model most extensively and their responses to these items were very positive, indicating that they found these chemical representations to be the most powerful tools for representing organic compounds and most beneficial to their learning. Responses of greater than 80% for the combined agree and strongly agree categories were obtained for the ball and stick model's ability to show what the molecule looked like (90%, item 1); show its shape and structure (91%, item 3); show the existence of chemical bonds (95%, item 4) and generate a picture in their mind (95%, item 6). The students appreciated that the computer-modelling program was a very useful representation too, but they were aware of its limitations in that it was a representation of the real thing. The more reserved responses for the space-filling models were probably because they were not used routinely in the lessons and students did not have the opportunity to manipulate them. Despite this, many students appreciated their value, especially in generating a picture of the molecule in their mind (72%, item 6). But students also were aware of the limitations of the space-filling models with only 19% agreeing that this representation showed how the molecule behaves (item 2).

(Insert Table 1 about here)

The results of the instrument, *My Views on Models and Modelling in Science*, showed that many students (>80%) concluded that a model is 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) (see Table 2).

(Insert Table 2 about here)

The reasons given to validate students' responses on the instrument *My Views on Models and Modelling in Science* were mostly logically sound arguments that supported their responses. Examples of students' reasons supporting the answer, that models are representations, included "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".

When considering the future of a model, students' reasons for their choice included "Facts may change due to technology", "Models 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". Students referred to scientific models with respect to their role in the scientific world.

Analysis of qualitative data

As previously stated, during the lessons students worked with several teaching models - structural formula, ball and stick models, a computer program, and the space-filling models - to help determine nomenclature, the structure and the properties of simple organic molecules. While initially using the ball and stick model to represent organic hydrocarbons, students became familiar with the bonding rules and constructed feasible compounds. Students observed that no matter how they manipulated the model of hexane, for example, it would not form a 'straight' chain. This observation, along with rotating all the atoms in a compound, made it possible to view the structure from a different perspective, which helped students to understand the significance of the angles between the atoms in the organic compounds. Students discovered several structures obeying the same general formula, thus identifying isomers - different structures with the same general formula - although they had not been instructed in this nor did they know the term 'isomer'. Later, more detailed isomers were investigated with comments like "so it does matter what side you stick them (the model atoms) on" when referring to the *cis* and *trans* isomers of dichloroethene. Once acquainted with the three-dimensional nature of the compounds, the students began drawing the structural representations on paper, repeating this task with many different examples. This sequence of learning, beginning with the three–dimensional concrete model and then moving onto the two-dimensional drawings proved to be advantageous and is a suggested pedagogical sequence.

In this kind of learning opportunity, students developed their own mental models for the chemical structures. For example, students frequently returned to the ball and stick models to identify the longest chain of an organic molecule. Students were initially confused by the variety of equivalent structural formula representations such as butane-

$CH_3—CH_2—CH_2—CH_3$ and $\begin{array}{l} CH_3 \\ | \\ CH_2—CH_2—CH_3 \end{array}$

- and returned to the ball and stick model, manipulating the carbon and hydrogen positions to show their equivalence.

The video data showed students trying to rotate atoms around double bonds in response to a question about the implication of the double bond. A statement by a student towards the end of the unit: “Just do it on paper, we don’t need the model” could indicate a transference from physical manipulation to mental manipulation. Similarly, “No, if that’s the drawing then it’s not 1,1. Both of the -chloros aren’t coming off the first one so it can’t be 1,1”. The transference from the ball and stick model to the structural formula was practised repeatedly in the laboratory. Consequently, through the teacher’s encouragement to build ball and stick models and then draw the structural formula, students were able to make the link from 3D to 2D representations more easily and build up their mental models of the structure and motion of the molecules. With increased experience, students were able to build models quickly and manipulation of these teaching models provided students with an opportunity to discuss the structure and the nomenclature of each organic compound. The collaborative approach to learning was effective in promoting dialogue between students. This group activity contrasted to the students’ routine chemistry classes that were more teacher-centred. As illustrated in the following dialogue, students frequently repeated answers to each other, asking their partner for confirmation that they were correct.

S1: Next one you are gonna have two chlorines in the middle. That means 2,2 dichloropropane, it is all dichloropropane.

S2: This is what we have just done, it is still …

S1: It is all propane and it is dichloropropane and it is just the number and the fact that the number is 1,1; 1,2; 2,2.

S2: Perhaps 1,3 … What about 1,3?

S1: Fine. 2,2 is here and 1,2 is just like this.

S2: 2,3?

S1: No it will be 1,2

S2: I see. I did not realise what you were getting at it. It will be what?

S1: On what?

S2: 1,2; 1,3

S1: 1,2; 1,3

S2: and then 2,2; 1,2.

S1: What about 1,1; 1,2; 1,3 and that is it?

S2: Yeah

Students repeatedly counted along the model identifying the 'longest chain'. This was invaluable for naming compounds correctly, as in the example "1, 2, 3, 4, so it's butane, so it's methyl butane".

The transcripts of students' dialogue commonly included truncated phrases, with students often not completing sentences. The conversations, as displayed in this example indicated that students were communicating their understanding of the particular molecular structure to each other. This can be described as their expressed model.

S1: Yes, I think it is butene

S2: So the double chain, double bond is in different spots

S1: Double chain!

S2: Double bonds!!

S1: This is the one that was there before?

S2: This one is another one

S1: Is it?

S2: Yes definitely

S1: What is this one called?

S2: No, we made this one before

S1: Its methyl propene

S2: Oh damm

The following excerpt of transcript data supports the inference that students identified the positioning of the balls and sticks with the shape of the molecule.

S2 We have to do C6H14

S1Yeah

S1 1,2,3,4,5,6, He says there's five eh? (referring to the teacher claiming there are five possible isomers)

S2 We'll see

S1 This is hexane

S2 1,2,3,4,5,6, Yeah that's got six -Then it goes straight on.

S1 Just change the position of one of them

S1 I did that and altered the shape

S2 No you actually have to pull a bit off

S2 You got it yet? Have you changed it around?

S2 Then what would that equal?

S2 1,2,3,4,5, five is your longest chain and you've got one coming out

S1 Methylpentane - it doesn’t sound right.

Similarly, the student’s comment “I don’t know but it’s connected, sharing electrons” implies that the student connects the representation of the region between a two balls with a covalent bond:

The computer-modelling program was used to reinforce work already covered in the classroom and to present it in a slightly different format providing alternative and dynamic representations of organic compounds at the push of a button. Students’ comments support this assertion with the following comments: “We could make half of these”(259), referring to the ball and stick type images on the computer screen; and references to the random movement of the molecules across the screen:

S1: Do you think that can zoom out to real size?

S2: Oh maybe

S1: Keep going

S2: 1 chlorobutane

S1: ah it’s coming right for me!

S2: You feel like you are going to collide with it. (173-181)

The use of alternative representations provided opportunities in helping the students construct their mental model.

Summary of results for Theme 1

The qualitative and quantitative data provide support that students had developed a sound understanding of how scientific and teaching models work. The researchers interpreted the data to indicate that the teaching models of simple organic molecules served as valid descriptive tools of scientific models, which in turn are a manifestation of the scientific theory and assisted these students in developing their own mental or conceptual model.

Theme 2: Students only developed a limited understanding of the predictive nature of teaching models.

Analysis of quantitative data

In contrast to the majority of students' understanding the role of models used in the process of science in responding to the *My Views of Models and Modelling in Science* instrument, responses to the *Molecular Representations* instrument (see Table 1) revealed that only a small percentage of students identified that each teaching model could be used to test ideas, make predictions and solve problems. Between 19-50% of students responded, 'don't know' to items investigating these attributes (items 9 -11). The majority of students gave no definitive response to these questions, indicating that they did not have a clear concept of teaching models as tools for testing ideas, solving problems or making predictions.

Students' written explanations to justify their responses in the instrument *My Views of Models and Modelling in Science* revealed aspects of their epistemology of the process of science. Many students gave meaningful and thoughtful reasons to support their choice but no student commented on the predictive aspect of models. The definition of a model as a representation was supported by reasons such as, "a model is not always accurate, but it gives ideas of how things work and visualise and create images in mind".

Some comments revealed a more simple understanding; for example, one student reasoned "the compounds in real life are not as big as the models used in class so it's just a representation". Another student supporting her choice that a model is an accurate duplicate of reality says "because that is how they are represented in the Chemistry textbook, (the) 'bible' (for our course)". In response to why scientists use more than one model, one student responded that, “Some models explain different aspects of phenomena to a greater extent than others; therefore relevant models are chosen to get the best explanation for separate matters if needed”. There were comments on the process of change in scientific thinking, for example, “Many models introduce new ideas - interesting” and “Technology is advancing - might discover new things they did not know”. A small number of students expressed negative attitudes towards chemistry. For example, in response to the acceptance of new scientific models, a student claimed “it is just politics” and “Scientists may think that they are smart and know everything --- but not really!” These responses show that students do think about models further than their descriptive nature but this did not include the predictive nature of models.

Analysis of qualitative data

There are examples of students using the ball and stick models to predict the molecular arrangements of various isotopes and to help name compounds, for example to determine the possible isomers for the compound $C_3Cl_2H_6$.

S1: There is one structural formula and now I am about to modify it

S1: Chloro-propene

S2: Propene 3 right?

S1: Ethene propene butene

S2: Did you modify it?

S1: Yes I did (262)

S2: How did you modify it?

S1: If you look at my structural formula you will see

S2: Do you mean it’s exactly the same?

S1: No it’s not.

S2: Ah Its…very nice,,…switched

S1: and we will now switch again, just as long as I fix this to not repeat. This shall be easy

S2: yes

S2 Do you mean it's exactly the same

S1: If we stick a CH_3 bond on the same side as the double bond as the chlorine

S2: I've already done that

S1: We have…atoms 4

S2: I say you put them both on the top,- one on the bottom one on the top and both on the same side trans chloropropene and then we have cis-chloro-propene.

This dialogue shows that these students are developing an understanding of what an isomer is and also that the there is no rotation allowed around the double bond thus producing alternative compounds. In this activity, the students used the teaching models to predict possible isomers.

At the conclusion of the unit, the teacher administered a practical test on molecular models. The students, working under test conditions, were required to make ball and stick models of particular compounds. For example:

Question 2: Construct a model for ethane. Try to rotate the end of the molecule about the C-C bond. Record your observations. Draw the structural formula for ethane.

This test was videotaped with both classes and the observations showed students using the teaching models' physical characteristics to help explain the chemical characteristics of organic compounds such as to determine the degree of rotation allowed about a single and double bond, to investigate the angles of the tetrahedral arrangements of bonds coming from a carbon atom and counting the number of carbon atoms in the compound. Students had the ball and stick models in front of them while they were drawing the structural formulas on paper and compared both representations. The video record clearly showed students using the teaching models to make predictions and determine the answers to the questions in the test.

Summary of results for Theme 2

The quantitative results of the *Molecular Representations* instrument seem to conflict with the qualitative data whereby in class students were observed to use the ball and stick models to help name molecules, make predictions about a compound's reactivity, for example by identifying the site of double bonds, and making predictions about a compound's stability by looking at bond angles. A possible explanation is that the Year 11 students undertook these activities without realising that they were using the teaching models to test ideas, make predictions and solve problems. Evidently, the students did not relate the attributes of the *teaching* models to the familiar attributes of *scientific* models, which the majority of students had expressed in the qualitative data. The other inference is that the students have a clear understanding of the theoretical roles and attributes of *scientific* models but had not been able to recognise the predictive attributes of the *teaching* models that they were using. From these results, we can propose that students see *scientific* models and *teaching* models to be different. Consequently, the need to explicitly highlight these predictive uses in *teaching* models appears necessary, as the students readily followed instruction, using the models to answer chemical questions without appreciating the value of the model in determining this knowledge. These results imply that these students' theoretical understanding of the scientific model is not necessarily related to practical applications of the teaching model.

Conclusion

This study investigated secondary students' understanding of the descriptive and predictive nature of teaching models using a variety of chemical representations while learning organic chemistry. The discussion, manipulation, naming and drawing of the chemical representations all worked together to help the students construct their own mental models as evidenced by student responses to interviews and questionnaires that differentiated the attributes of the various teaching models used. The majority of students exhibited a sound appreciation of the descriptive nature of those teaching models. However, given the low positive response about how these students view models for testing ideas and making predictions on the *Molecular Representations* instrument, and how competently the students used the teaching models in the lessons, it is hypothesised that they had not realised that they had been testing ideas and making predictions during the lessons with the models. This difference highlights a lack of application of conceptual understanding and suggests a need for greater emphasis on practical uses of teaching and scientific models. Consequently, a suggested approach is for the teacher to overtly explain, when appropriate, that students are using these teaching models to predict, test or evaluate conceptions and that scientists use scientific models in similar ways.

Raghavan and Glaser (1995) working with sixth grade students, reported an improvement in the development of students' model-based reasoning skills in predicting, testing and evaluating ideas as a result of specific model-based instruction. Their instruction did include "a discussion to introduce models as important tools for scientists, who must work with many things that cannot be directly observed and who use models to understand and to explain to others" (p. 45) whereas this present study focused on the chemical concepts that had to be learned and the models used as tools to that end. This difference in findings suggests that scientific models should be displayed in a more active role as concluded by Grosslight et al. (1991) who expressed a need to “provide students with the experiences of using models to solve intellectual problems” (p. 820).

The specific strategies adopted by the teacher provided fruitful learning experiences for students. First, the sequence of learning where initially all students manipulated three-dimensional models and then drew two-dimensional drawings has pedagogical merit. Second, repeated practise at representing and naming chemical compounds resulted in students learning chemical subject matter. Third, the collaborative tasks encouraged students’ discussion and the tape-recorded discussions showed that students were learning from each other. In addition, the computer-generated representations were mostly graphic, but the students’ use of them was superficial, most likely because this work was done outside the laboratory and only a small amount of direction was provided.

The data from the *My Views of Models and Modelling in Science* (VOMMS) instrument suggest that students linked teaching models with scientific models at a theoretical level. When considering model types, teaching models play a pivotal role in accessing scientific models, and subsequently help students develop their own mental models of the phenomena being investigated. Teaching models as well as scientific models can serve as descriptive and predictive tools, which are a manifestation of the relevant scientific theory.

Simple chemical representations used as teaching models in the chemistry laboratory play an important role in student learning. Students’ mental and expressed models are impacted by their experiences with such teaching models. The majority of students in this study were able to identify the descriptive nature of the teaching models that they had used and recognised the benefit of using numerous representations. However, the majority of students did not recognise the predictive nature of the teaching models despite using them in a predictive fashion in their chemistry class. This finding highlights the difference between using a teaching model as a tool to provide an answer in response to a question and understanding the role of a teaching model in this conceptual process.

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Table 1 – see separate file

Table 2

Results of the instrument My Views on Models and Modelling in Science (n=36)

Statement	%
1) Models and modelling in science are important in understanding science. Models are:	
representations of ideas or how things work	86.2
accurate duplicates of reality	8.3
2) Scientific ideas can be explained by	
a) one model only, - any other model would simply be wrong.	2.8
b) one model, - but there could be many other models to explain the ideas	91.7
When scientists use models and modelling in science to investigate a phenomenon, they may:	
use only one model to explain scientific phenomena.	16.6
use many models to explain scientific phenomena.	80.6
When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:	
based on the facts that support the model and the theory.	83.4
influenced by their personal feelings or motives.	11.1
The acceptance of a new scientific model :	
requires support by a large majority of scientists	19.4
occurs when it can be used successfully to explain results	72.3
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:

will not change in future years.	2.8
may change in future years.	88.9

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.

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