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Investigating the Relationship between Students' Views of Scientific Models and Their Development of Models

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Understanding the nature of models and engaging in modeling practice have been emphasized in science education. However, few studies discuss the relationships between students' views of scientific models and their ability to develop those models. Hence, this study explores the relationship between students' views of scientific models and their self-generated models, and also whether views of models and modeling practice may be influenced by other factors, such as science learning performance and interest. The participants were 402 ninth-grade students in Taiwan. Data were collected using the Students' Understanding of Models in Science (SUMS) survey and students' self-evaluations of their own science learning interests and performance on a Likert-scale. The students' self-developed models explaining why three different magnetic phenomena occur were also evaluated on a schema of five levels, from lower (observational and fragmented models) to higher (microscopic and coherent models).The results reveal that most students' models remained only at the level of description of observable magnetic phenomena. A small number of the students were able to visualize unseen mechanisms, but these models were fragmented. However, several students with better science learning performance were able to develop coherent microscopic models to explain the three magnetic phenomena. The analyses indicated that most sub-factors of the SUMS survey were positively correlated with students' self-developed models, science learning performance and science learning interest. This study provides implications for teaching the nature of models and modeling practice.

Keywords: *Magnetism; Model construction; Modeling practices; The nature of models and modeling*

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Introduction

Research has found that when students have a more sophisticated understanding of the nature of science, they also exhibit better conceptual learning in science (Clough, 2006; Deng, Chen, Tsai, & Chai, 2011; Kim & Irving, 2010; Songer & Linn, 1991; Stathopoulou & Vosniadou, 2007). Models and modeling are generally considered to be an important aspect of science, and thus the epistemology of scientific models is an essential part of the epistemology of science and scientific literacy (Akerson, White, Colak, & Pongsanon, 2011; Lederman, 2007; National Research Council [NRC], 2007, 2012; Next Generation Science Standards Lead States [NGSS], 2013).

Although both the understanding of the nature of models and skills in modeling practice have been emphasized as major goals in science education and research (Nicolaou & Constantinou, 2014; NGSS, 2013; NRC, 1996), few studies discuss the relationship between the two or investigate whether they are associated with students' science learning in school. Hence, in order to enhance model-based teaching and learning, the aim of this study is to investigate the relationships between students' views of scientific models and their ability to develop such models. Further, the study will also explore whether students' science learning performance or interest are associated with their views of or their ability to develop scientific models.

Theoretical Background

Epistemology of Scientific Models

In prior research on the *epistemology of models and modeling* (Crawford & Cullin, 2005; Grosslight, Unger, Jay, & Smith, 1991; Grünkorn, Upmeier zu Belzen, & Krüger, 2014; Krell, Upmeier zu Belzen, & Krüger, 2014; Oh & Oh, 2011; Schwarz et al., 2009; Schwarz & White, 2005; Treagust, Chittleborough, & Mamiala, 2002), scientific models are seen as a tool to represent mechanisms or interactions in order to explain and predict target phenomena. That is, they are not only products of science but also tools and processes of science. Researchers have employed different terms to refer to this kind of knowledge; the understanding of the nature of scientific models and modeling processes is referred to in this article as their views or understanding of scientific models.

Our understanding of models and modeling has been broken down conceptually into several aspects, and across aspects, researchers have used different scales to show different levels of understanding, reflecting the constructivist epistemology of science. Although different researchers may define or break down the epistemology of scientific models differently, the following three commonly considered aspects emerge from the existing research: the *nature of models*, the *purpose of models*, and the *process of modeling*. Across these aspects, a lower level of understanding has been considered consistent with a naïve-realist epistemology in which models are perceived as physical copies of target phenomena, while a higher level of understanding is consistent with a constructivist framework in which models are perceived as research tools used to produce theoretical representations of ideas (Grosslight et al., 1991; Krell et al., 2014).

The Nature of Models

The study of the nature of models focuses on understanding the relationship between a model and a target phenomenon, including consideration of ontological beliefs about models as theoretical representations of target events and the implications of the existence of multiple models to represent the same target event (Grosslight et al., 1991; Krell et al., 2014; Treagust et al., 2002).

With respect to ontological beliefs about models, Grosslight et al. (1991) and Oh and Oh (2011) discuss what models and their target events can and cannot be as well as the relationship between the model and the target event(s). Scientific models do not reflect or express the target events exactly, but instead represent them in a simplified way as abstract ideas. A model can also be understood as a bridge between a scientific phenomenon and a theory, that is as a tool that provides insight on the basis of which to develop a theory from existing data (Oh & Oh, 2011). Therefore, according to Bailer-Jones (2003), models should not be judged by the verisimilitude with which they represent target events, but instead as heuristic devices used to represent the target(s) in a way that facilitates perceptual and intellectual access. For example, the particle model of light is an example of a scientific model that visualizes unseen entities and mechanisms that are not observable in the target phenomena. The main point of the model is not whether light really looks like a particle, but to make a rational hypothesis to imagine a non-existent entity in a way that facilitates intellectual access to the target event.

Researchers have found that many students have what is called a naïve-realist view of scientific concepts, meaning they do not make an ontological distinction between target events in the real world and entities created for the purpose of model-building (Grosslight et al., 1991; Sins, Savelsbergh, van Joolingen, & van Hout-Wolters, 2009). They focus on the representations as they appear in the models and consider the models to be simple copies of reality (with the purpose of matching the appearance or nature of target objects). In other words, they consider the model identical to the target phenomenon. Conversely, when students have the highest level of understanding in this scheme, they see a model as a theoretical abstract representation of the target event (Krell et al., 2014).

The existence of multiple models for the same target phenomena indicates that there is not a single valid scientific way of viewing a phenomenon (Crawford & Cullin, 2005; Grosslight et al., 1991; Oh & Oh, 2011; Treagust et al., 2002). Researchers have indicated the reasons for the multiplicity of scientific models: because different models are needed to represent different aspects of phenomena, to provide more complete explanations, and to offer different ways of explaining the same target event (Crawford & Cullin, 2005; Oh & Oh, 2011).

For many students, with a lower level of understanding of the multiplicity of scientific models, differences between models of the same phenomenon seem to be interpreted either as structural differences between the models themselves or in terms of their perspective and way of focusing on the target. At a higher level of understanding, multiple models are considered to each have different hypotheses or types of utility for the same phenomena (Crawford & Cullin, 2005; Grosslight et al., 1991; Krell et al., 2014; Oh & Oh, 2011; Sins et al., 2009).

The Purpose of Models

The purposes of scientific models are multiplicitous, and views of them vary. Models have been perceived as generative research tools for explaining, predicting, or visualizing scientific phenomena, and as thinking and communicating devices for formulating, reasoning, testing, revising, and communicating ideas in science (Grosslight et al., 1991; Krell et al., 2014; Oh & Oh, 2011; Schwarz et al., 2009; Sins et al., 2009).

There are various levels of understanding reflected in the assumed purposes of models. At the lowest level, models are employed merely to show and match the appearance of target objects (Grosslight et al., 1991). At a somewhat higher level, models are employed with a specific purpose and are understood to not correspond exactly with all properties of the target phenomena (from Nicolaou & Constantinou, 2014; Sins et al., 2009). At the highest level, models are employed as abstract representations that explain and predict scientific phenomena (Schwarz & White, 2005). In other words, a scientific model used as a research tool is being applied to its most sophisticated purpose (Krell et al., 2014).

The Process of Modeling

The process of scientific modeling is an iterative process of construction, evaluation, and revision or replacement of models. In this understanding, models are tentative and subject to further revision and replacement if they do not correspond to empirical data or if the target phenomena are interpreted in different ways (Clement, 2008; Crawford & Cullin, 2005; Halloun, 2004; Oh & Oh, 2011; Sins et al., 2009). These models can then be assessed based on their empirical fit with the target phenomena and revised accordingly. If a model has difficulty explaining or predicting the data, it is considered to need revision or replacement. A model is also evaluated based on consistency with other accepted models, theories, or knowledge. If a model cannot meet these criteria, again, it may be discarded or modified (Crawford & Cullin, 2005; Halloun, 2004; Oh & Oh, 2011; Passmore, Stewart, & Cartier, 2009; Stewart, Cartier, & Passmore, 2005).

As indicated above, at a lower level of understanding of the modeling process, the focus of modeling is considered to be straightforwardly descriptive, centering on either (1) the testing and modification of model objects themselves for known events or on (2) the comparison of known properties or processes of target events with their representation in models and the revision of the models on the basis of new insights or information yielded thereby. At a higher level of understanding, the focus of modeling is explanatory and predictive, aimed at unknown mechanisms and centering on evaluating and revising hypotheses for target events according to continuous empirical and conceptual assessment (Grünkorn et al., 2014; Krell et al., 2014).

In short, the 'expert level' of scientific understanding recognizes that models are employed as a device for developing and evaluating ideas rather than for copying reality. As students achieve a higher level view of models and modeling, they come to perceive models as a scientific research tool and theoretical representations (Krell et al., 2014; Treagust, Chittleborough, & Mamiala, 2004). As a result, they come to understand how models can be manipulated and changed in order to better predict and explain target phenomena (Sins et al., 2009).

Empirical Studies of Students' Understanding of Models

According to empirical studies on students' understanding of scientific models and modeling, most secondary students have a narrow view of epistemology, perceiving scientific models as physical copies of target events in the way described above (Grosslight et al., 1991; Sins et al., 2009; Treagust et al., 2004). Some researchers, further, break down students' epistemological understanding of scientific models into several different aspects (e.g. the nature of models, the purpose of models, and the process of modeling), allowing different levels of student understanding and performance to be distinguished. These studies indicate that secondary students have a better understanding of the process of modeling than they do of the nature or the purpose of models (Gobert et al., 2011; Grünkorn et al., 2014; Krell et al., 2014; Treagust et al., 2002).

Relationships between Understanding of Models and Model Development

Numerous studies have found that students' epistemological understanding of the nature of science is related to their conceptual understanding in science (e.g. Clough, 2006; Deng et al., 2011; Kim & Irving, 2010; Schwarz & White, 2005) and their practice of scientific inquiry (e.g. Deng et al., 2011; Sandoval, 2005; Schwarz & White, 2005; Windschitl, Thompson, & Braaten, 2008). Since model and modeling has been regarded as an important aspect of science, there have been studies focusing on the epistemology underlying scientific models (Grosslight et al., 1991; Krell et al., 2014; Treagust et al., 2002) or the practice of modeling (Bamberger & Davis, 2013; Louca, Zacharia, Michael, & Constantinou, 2011; Schwarz et al., 2009; Schwarz, Reiser, Acher, Kenyon, & Fortus, 2012). However, there is a lack of research on the relationship between these two.

Some researchers have speculated that students' understanding of scientific models may be related to their practice of modeling (Schwarz et al., 2009, 2012), or that students' understanding of models may shape their modeling practice (Crawford & Cullin, 2004; Nicolaou & Constantinou, 2014). However, other researchers have argued that there is no empirical evidence to support the above suppositions (Krell, Reinisch, & Krüger, 2015; Louca & Zacharia, 2012). Thus, the present study sets out to explore whether there is any relationship between middle school students' understanding of scientific models and their practice of modeling. In order to explore students' modeling practice, the current study required students to self-generate their own mental models to account for scientific phenomena so as to assess students' abilities to develop their own models.

Another group of studies has investigated the relationship between students' views of scientific models and their science learning. The results of such studies indicate that students with a higher-level epistemology of scientific models will have better scientific content knowledge (Gobert et al., 2011; Gobert & Pallant, 2004; Park, 2013; Schwarz & White, 2005), deeper cognitive processes in modeling tasks (Sins et al., 2009), and higher grades in science (Krell et al., 2014). In addition, students' epistemological understanding of science, science learning performance, and science learning interest have been considered relevant, because studies have indicated that teaching the nature of science is a way to enhance students' content knowledge and to increase their learning interest (Erduran & Dagher, 2014; Seker &Welch, 2006; Teixeira, Greca, & Freire, 2012). Thus, the present study sets out to explore whether there is any relationship between students' understanding of scientific models, practice of modeling, and other factors, namely science learning performance and science learning interest.

Research Questions

These following two research questions help us better uncover the relationship between students' views of scientific models and their ability to develop such models.

(1) What are students' self-generated models for magnetism? Do students with better science performance and science learning interest in school develop microscopic, coherent models?
(2) What is students' understanding of models in science? Do students with better science performance, better science learning interest, or greater ability to develop scientific models, have better understanding of models in science?

Methods

This study was conducted among a total of 402 ninth-grade students recruited from three middle schools in central Taiwan. These students did not receive any special instruction on the nature of scientific models and on scientific models of magnetism, such as scientific domain or atomic models of magnetism. Students' responses are therefore inferred to be based on the general science courses and curriculum they have taken, because this study investigates students' understanding of scientific models and modeling based on their science learning in general and their ability to self-generate models of magnetism.

In order to examine the relationships between (1) students' views of the nature of models, (2) their ability to develop models, and (3) their science learning performance and learning interest, the data collection includes a written survey about students' self-generated models of magnetism as well as a Likert-scale survey about their understanding of models in science and their self-evaluation of their own science performance and learning interest.

Instruments of Assessment

Students were asked to take 25 minutes to fill out the following surveys. First, they were asked to fill out a survey about their current understanding of scientific models, without being offered examples of scientific models or being led to think about any specific science domain. Next, students were asked to self-develop the best models they could to account for three magnetic phenomena, without being provided with a scientific model of magnetism.

Students' self-developed models of magnetism. In order to determine whether students can develop models to explain observed phenomena as scientists do, students were asked to explain three different magnetic phenomena: (1) Which parts of a bar magnet can attract iron nails? (2) Why do ordinary iron nails not attract other iron nails? (3) Why can iron nails attract other iron nails after being attached to the bar magnet? Students needed to write and draw explanations for each individual question, which was meant to assess their ability to develop mental models for different magnetic phenomena. A 'mental model' here refers to an internal representation of the target phenomena, which will be externalized and conveyed through students' drawing and writing.

Students' writing and drawing were coded by three researchers specializing in physics education in order to develop a consistent coding system and interpretation of students' self-generated models of magnetism. Models were assessed according to quality, based on the degree to which and the way in which the model reflected two features: (1) an underlying mechanism and (2) coherence. The presence of these was deemed to be characteristic of how actual physicists developed scientific domain or atomic models of magnetism at the microscopic level in order to coherently explain observed magnetic phenomena. Thus, models which included an underlying mechanism at the microscopic level were regarded as more advanced than those describing observational phenomena, while models that could coherently explain a larger range of observations were regarded as more advanced than those that only explained a single phenomenon (Cheng & Brown, 2010, 2015; Machamer, Darden, & Craver, 2000; Russ, Scherr, Hammer, & Mikeska, 2008). To reflect these considerations, students' models were classified into five levels, ranging from lower (observational and fragmented models) to higher (microscopic and coherent models), as illustrated in Table 1.

A 'microscopic model' in this study is one that takes a particle perspective to explain the underlying mechanism of a scientific phenomenon. In physics, the mechanism of a phenomenon is considered to be governed by macroscopic constitutive laws based on observation, through which microscopic origins are always under exploration (Alloul, 2011). Unobservable microscopic entities and interactions have thus been employed

Table 1. Levels of scientific models

Level	Definition	Example
1	Description of observable magnetic phenomena	Student only described the fact that the two magnets had two strong ends to attract the iron nails.
2	Visualization of unseen and unknown elements to explain magnetic phenomena	Student imagined an unknown special material in the magnet to explain the attraction of the magnet.
3	Visualization of unseen microscopic elements to explain only one specific magnetic phenomena	Student visualized one specific type of microscopic element, such as N–S dipole components, N and S monopole components, or positive and negative electric monopole components, inside the magnet and the nails to explain why the magnet attracts the nails.
4	Visualization of unseen microscopic elements to explain only two specific magnetic phenomena	Student visualized one specific type of microscopic element inside the magnet and the nails to explain not only why ordinary iron nails would not attract other iron nails but also why these nails attracted other iron nails after they were attached to the magnet.
5	Visualization of unseen microscopic elements to explain all three magnetic phenomena	In addition to the visualization in Level 4, student visualized the alignment of the microscopic elements in the magnet to explain the two strong ends of the magnet.

to explain observed scientific phenomena, such as thermodynamics (Haglund & Jeppsson, 2012), gas law (Kautz, Heron, Shaffer, & McDermott, 2005), the concept of energy (Ding, Chabay, & Sherwood, 2013), and electricity (Guisasola, 2014). In order to explain observable magnetic phenomena, physicists have attributed the origin of a magnetic state to electron spin or magnetic moment at the microscopic level (Alloul, 2011; Chabay & Sherwood, 2006; Dai, Hu, & Dagotto, 2012; Durkan, 2004). Accordingly, as students in this study visualized the behavior of atom or particles, their models were classified at a microscopic level.

In Table 1, for Levels 1–3, students' models were classified according to whether they described observable events only, visualized unknown material, or visualized microscopic elements. For Levels 3–5, models were classified based on whether students visualize an unseen mechanism at the microscopic level to explain one, two, or all three magnetic phenomena. Higher levels of model showed that students could develop more coherent microscopic models. For initial coding, the consensus between three researchers was 0.86. Rating inconsistencies were resolved during coding.

Students' understanding of models in science. Students were also asked to complete the Students' Understanding of Models in Science (SUMS) survey (Treagust et al., 2002), which was adopted to assess their epistemological understanding of scientific models. This tool was chosen because it is a comprehensive survey that covers major aspects of the nature of models and modeling (the nature of models, the purpose of models, and the process of modeling). The categorization of different aspects of the understanding of scientific models allows us to further investigate which aspects are related to students' practice of modeling and science learning in school, to what degree, and how.

The SUMS survey is based on empirical studies of how best to promote the understanding and use of models in science (Grosslight et al.,1991; Treagust et al., 2002). The survey investigates students' understanding across five sub-factors: 'multiple representation of models'(MR), 'models as exact replicas' (ER), 'models as explanatory tools' (ET), 'use of scientific models' (USM), and 'changing nature of models' (CNM). This survey asked students to rate the items on a (five-point) Likert-scale, (1 = *strongly disagree* to 5 = *strongly agree*). A higher score represents a better understanding of the nature of the models in terms of that sub-factor, except for ER, in which higher scores indicate a more naïve understanding of scientific models. The reliability of the individual SUMS scales in Treagust et al.'s study ranged from 0.71 to 0.84. In the present study, each scale also had a high internal consistency: reliabilities ranged from 0.72 to 0.81.

In addition to the SUMS survey, students were asked to evaluate whether they performed well in their science learning in school and whether they had high learning interest in science, on a (five-point) Likert-scale, (1 = *strongly disagree to* 5 = *strongly agree*). A higher score represents better performance or learning interest in science.

Data Analysis

In order to answer the first research question, Pearson correlation analyses were carried out to investigate the relationships between the levels of students' explanatory models as well as their science learning performance and interest. Then, a comparison table was constructed to compare the distribution of different levels of model by science learning performance and interest. Next, a one-way analysis of variance (ANOVA) was conducted to explore whether there were any significant differences between students' science learning performance and interest according to their self-developed models. *Post-hoc* analysis with the Games–Howell tests was employed to do comparison between students with different levels of models.

In order to answer the second research questions, Pearson correlation analyses were conducted to examine the relationships between students' understanding of scientific models as well as their science learning performance and interest and their self-developed models. ANOVA was conducted to investigate whether there were any significant differences in students' understanding of models by science learning performance and interest and by the features of their self-developed models. Bonferroni *post-hoc* tests were employed to compare students with different science learning performance, interest, and levels of model.

Results

Levels of Self-Generated Models

The results revealed that most students' self-generated models (88.1%) were only at Level 1, describing observable magnetic phenomena (see Figure 1). At this level, students usually described the magnet as pulling the iron nails to its two ends or to any part of the magnet, without visualizing an unseen mechanism to explain magnetism.

Only a small number of the students (11.9%) were able to visualize unseen mechanisms in their models, placing these models between Level 2 and Level 5. At Level 2, students started to visualize special materials in iron nails or the magnet in order to explain the attraction of the magnet, without specifying whether these materials were microscopic or not. At Level 3, students started to imagine an unseen microscopic mechanism, such as static electricity charges, in the magnet or the nails. However, at this level, they could only use the model to explain one observed magnetic phenomenon, most often describing microscopic elements as passing from the magnet to the nails to enable the magnet to attract the nails. To explain the other two magnetic phenomena, they still provided only the descriptions of observable events. At Level 4, students used the concept of microscopic charges to explain two magnetic phenomena: how the original nails lacked charges without an attraction, and how the charges pass through the nails to enable them to attract other nails. Although in the models from Level 2 to Level 4 students could start to visualize an unseen mechanism, these models were still utilized to explain only one or two magnetic phenomena, and were thereby considered to be fragmented models, unable to explain all observed magnetic phenomena.

At Level 5, even fewer (0.7%) students could develop a coherent microscopic model for the three magnetic phenomena. Most students who developed Level 5 models in this study employed a model similar to the static electricity model to coherently explain magnetic phenomena. In this model, students considered the positive and negative charges at the N and S ends of the magnet that enable it to pull the iron nails to its two ends. The charges flowing from the magnet to the nails enables them

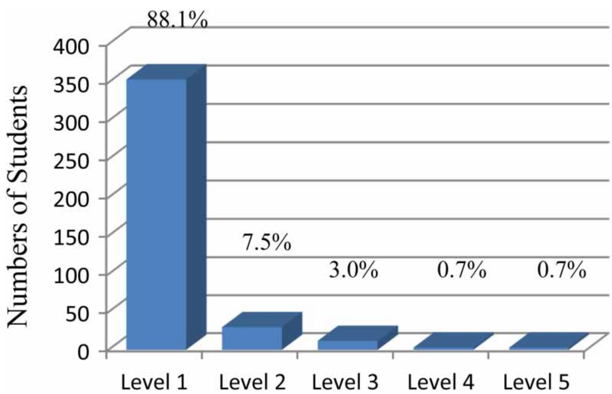

Figure 1. The number and proportion of students at different model levels

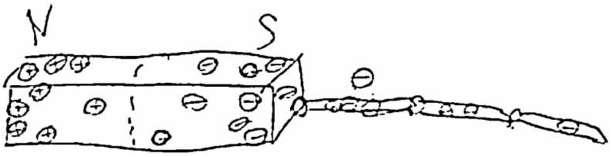

Figure 2. Example drawing from a student who developed a Level 5 model of magnetism

to stick to each other in a chain and to attach to the magnet (see Figure 2). Given the view that students visualized unobservable charges at the microscopic level and employed this model to explain all three different magnetic phenomena—two strong ends of the bar magnet, unmagnetized iron nails, and the process of magnetization of iron nails—this model was classified as a Level 5 model.

Model level had a low positive correlation for both their science learning performance and interest (0.203 and 0.226, respectively). In order to identify the reason(s) underlying this low correlation coefficient, five levels of the model were compared with students' self-evaluation of science learning performance and interest (see Table 2).

Table 2 shows that when students had lower levels of science learning performance and their interest was below average, most of their self-generated models stayed at the observation level (Level 1). In contrast, only students, whose science learning performance and interest were average or above average were more likely to visualize unseen microscopic elements in models equal or above Level 3. Only a few students who had above average science learning performance and high interest in learning science were able to develop coherent microscopic models at Level 5 for each of three different magnetic phenomena. In other words, even though most of the students claimed that they had high learning performance and interest in science, the majority of them were unable to develop Level 5 models.

The ANOVA indicated that the variation in students' learning performance and interest based on the levels of their self-generated models was significant ($F(4,397) = 4.786$, $p < 0.001$ vs. $F(4,397) = 6.450$, $p < 0.001$). *Post-hoc* analysis revealed that students who developed microscopic models at Level 3, 4, and 5 had significantly better science learning performance ($M3p = 3.42$, $M4p = 3$, $M5p = 4.33$) and interest ($M3i = 3.67$, $M4i = 3$, $M5i = 5$) than students who developed observational models at Level 1 ($M1p = 2.68$, $M1i = 2.80$).

Understanding of Models in Science

On the basis of the mean scores of each sub-factor of understanding of scientific models in Figure 3, most sub-factors (MR, ET, USM, and CNM) are close to an 'agree' response. Only ER is close to a 'not sure' response. The CNM sub-factor has the highest mean score ($M_{\mathrm{CNM}} = 4.05$), which implies that students had a better understanding of the changing nature of scientific models, and the ER sub-factor

Table 2. Comparison of scores for perception of scientific models by science learning performance and interest

	Five-point scale	Level of Model					
		Level 1, (%)	Level 2, (%)	Level 3, (%)	Level 4, (%)	Level 5, (%)	Total, (%)
Science learning performance	1	43 (10.7)	1 (0.2)	0 (0)	0 (0)	0 (0)	44 (10.9)
	2	103 (25.6)	5 (1.2)	0 (0)	0 (0)	0 (0)	108 (26.9)
	3	143 (35.6)	17 (4.2)	**8 (2)**	**3 (0.7)**	0 (0)	171 (42.5)
	4	55 (13.7)	6 (1.5)	**3 (0.7)**	0 (0)	**2 (0.5)**	66 (16.4)
	5	10 (2.5)	1 (0.2)	**1 (0.2)**	0 (0)	**1 (0.2)**	13 (3.2)
Science learning interest	1	45 (11.2)	0 (0)	0 (0)	0 (0)	0 (0)	45 (11.2)
	2	74 (18.4)	7 (1.7)	0 (0)	0 (0)	0 (0)	81 (20.1)
	3	156 (38.8)	13 (3.2)	**6 (1.5)**	**3 (0.7)**	0 (0)	178 (44.3)
	4	64 (15.9)	8 (2)	**4 (1)**	0 (0)	0 (0)	76 (18.9)
	5	15 (3.7)	2 (0.5)	**2 (0.5)**	0 (0)	**3 (0.7)**	22 (5.5)

Note: The bold values are essential findings described in the manuscript.

has the lowest mean score ($M_{ER} = 3.29$), which implies that students are not sure whether scientific models are exact replicas of target objects.

As shown in Table 3, the correlation analyses indicated that three sub-factors (MR, ET, and USM) had low positive correlations with science learning performance, interest, and self-developed models. ER was the only sub-factor correlated with students'

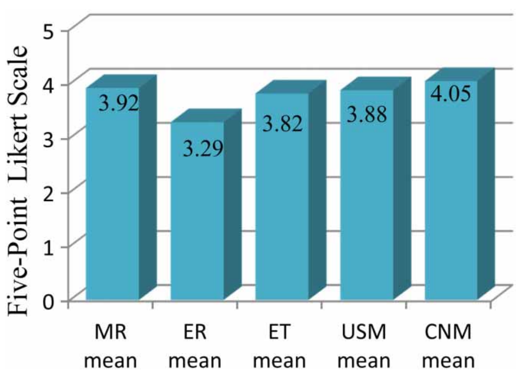

Figure 3. Mean scores of five sub-factors of SUMS (Treagust et al., 2002)

Table 3. Pearson correlations between students' understanding of models in science and their science learning performance, interest, and self-developed models

	MR	**ER**	ET	USM	**CNM**
Science learning performance	0.279**	**0.124***	0.268**	0.257**	**0.247****
Science learning interest	0.320**	**0.072**	0.287**	0.306**	**0.250****
Self-developed models	0.208**	**0.097**	0.221**	0.134**	**0.095**

Note: The bold values are essential findings described in the manuscript.

*$p < 0.05$.

**$p < 0.01$.

science learning performance, and CNM was the only one correlated with students' science learning performance and interest.

ANOVA indicated significant differences between all five sub-factors of students' understanding of models in science for their science learning performance (F_{MR}(4,397) = 8.79, F_{ER}(4,397) = 2.57, F_{ET}(4,397) = 8.95, F_{USM}(4,397) = 7.54, F_{CNM}(4,397) = 7.11, $p < 0.05$); a difference between four sub-factors of SUMS on their science learning interest (F_{MR}(4,397) = 14.528, F_{ET}(4,397) = 10.824, F_{USM}(4,397) = 12.881, F_{CNM}(4,397) = 8.329, $p < 0.05$); and differences between the three sub-factors of SUMS in terms of the self-developed models (F_{MR}(4,397) = 5.04, F_{ET}(4,397) = 5.44, F_{USM}(4,397) = 3.42, $p < 0.05$). In other words, most sub-factors (MR, ET, USM) related to students' perception of scientific models were significantly different with respect to science learning performance, learning interest, and self-developed models, with the exceptions being ER and CNM. Students did not have significant different views of ER based on their learning interest or their self-developed models, nor of CNM based on their self-developed models.

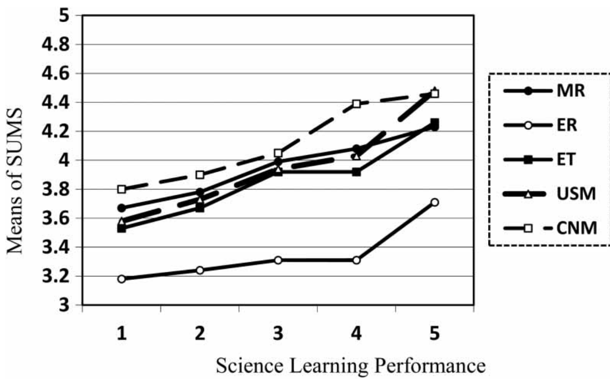

Figure 4. Means of each sub-factor of SUMS (Treagust et al., 2002) across students' science performance

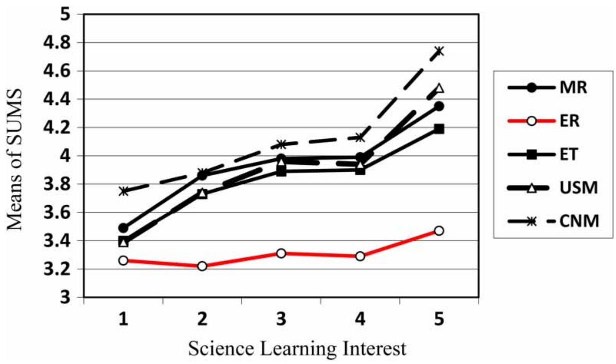

Figure 5. Means of each sub-factor of SUMS (Treagust et al., 2002) across students' science learning interest

The means of each sub-factor across students' different science performance are illustrated in Figure 4, different science learning interests in Figure 5, and different levels of self-developed models in Figure 6.

Post-hoc analysis (using an α of 0.05) showed that students who had the best science learning performance have significant higher scores for all five sub-factors of the scientific models ($M_{MR} = 4.23$, $M_{ER} = 3.71$, $M_{ET} = 4.26$, $M_{USM} = 4.48$, $M_{CNM} = 4.46$) than students who have the lowest science learning performance ($M_{MR} = 3.67$, $M_{ER} = 3.18$, $M_{ET} = 3.53$, $M_{USM} = 3.58$, $M_{CNM} = 3.80$)—indicating better understanding of MR, ET, USM, and CNM, but worse understanding of ER. Similarly, excepting ER, students who had the best learning interest also had a significantly better understanding of the other four sub-factors of the scientific models ($M_{MR} = 4.35$, $M_{ET} = 4.19$, $M_{USM} = 4.48$, $M_{CNM} = 4.74$) than students who had the lowest learning interest ($M_{MR} = 3.49$, $M_{ET} = 3.40$, $M_{USM} = 3.39$, $M_{CNM} = 3.75$).

Regarding the relationship between students' views of scientific models and the models they developed, *post-hoc* analysis also disclosed that students who developed

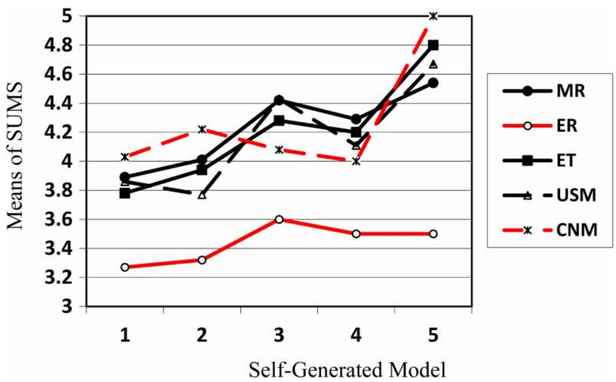

Figure 6. Means of each sub-factor of SUMS (Treagust et al., 2002) across the levels of students' models

microscopic models at Level 3 had significantly better understanding of MR, ET, and USM of scientific models ($M_{MR} = 4.42$, $M_{ET} = 4.28$, $M_{USM} = 4.43$) than students who developed observational models at Level 1 ($M_{MR} = 3.89$, $M_{ET} = 3.78$, $M_{USM} = 3.86$). Moreover, students who developed coherent microscopic model at Level 5 had significantly better understanding of ET ($M_{ET} = 4.80$) than students who developed observational models at Level 1 ($M_{ET} = 3.78$).

Discussion

This study was conducted to explore the relationship between students' views of scientific models and their ability to generate their own models. In this section, first, the models that students developed and the relationships between these models and their science learning performance and interest are discussed. Second, these factors and relationships are discussed in terms of their understanding of models in science.

Students' Self-Generated Models of Magnetism

The analysis of students' models of magnetism shows that most of them employed observational models to explain magnetic phenomena, without visualization of any unseen mechanism. Although some students considered themselves to have good learning performance and high interest in science, a majority of them were unable to develop coherent microscopic model. This research reveals that without offering students scientific models of magnetism, developing coherent microscopic models is difficult, even for students with good science learning performance and interest. The tendency to rely on observational models and the difficulty of developing and utilizing microscopic, coherent models have been identified even among college students (Chiou & Anderson, 2010; Ding et al., 2013).

In this study, a few students were able to develop coherent microscopic models, which were similar to the static electricity model, as also documented in several previous studies on students' models of magnetism (Guisasola, Almudi, & Zubimendi, 2004; Sederberg, 2012; Seroglou, Koumaras, & Tselfes, 1998; Voutsina & Ravanis, 2011). Even though this model is different from current scientific models of magnetism, the kind of model developed by the students can be seen as an intermediate stage between naïve ideas and properly scientific models; in fact, it is similar to models involving separation of elements between the two ends of the magnet that were proposed by the physicists Johan Wilcke and Anton Brugmans in the late eighteenth century (Johnson, 1999). Furthermore, the way that students borrow this model from another familiar domain of knowledge (static electricity) and visualize an unseen mechanism to coherently explain different magnetic phenomena is similar to the process of model-based reasoning to explain unfamiliar phenomena as used by scientists (Nersessian, 2008). Since these middle school students had not received any instruction in the scientific domain or atomic models of magnetism, it will be interesting for future research to examine differences in students' levels of model development before and after they learn the scientific models of magnetism.

As to the relationship between these models and the students' science learning performance and interest, this study found that only a relative few of the students who had shown above average science learning performance and interest in science were able to develop coherent microscopic models. In contrast, students with lower science learning performance and interest were only able to develop observational or fragmented models. Research has pointed out that experts tend to employ model-based reasoning and utilize organized and sophisticated models, while novices tend to employ reasoning based on the surface features of observed phenomena and to lack consistent and reliable models (Al-Balushi, 2009; Hsu, Lin, Wu, Lee, & Hwang, 2012). This is congruent with the current result indicating that students who could employ model-based reasoning similar to that used by experts had better science learning performance and interest.

For model-based reasoning at the microscopic level, studies have showed that facilitating students' understanding of mechanisms in the microscopic model improves their understanding of content knowledge (Corpuz & Rebello, 2011; Ding et al., 2013; Thacker, Ganiel, & Boys, 1999). Thacker et al. (1999) have hypothesized that this may be because understanding of macroscopic phenomena requires as a basis a coherent model of microscopic processes, which help students to overcome conceptual difficulty. The similar finding was identified in this study that utilizing an underlying mechanism at the microscopic level to account for scientific phenomena is associated with and may contribute to not only science performance but also learning interest in science. Nevertheless, the causal relationships, that is how this model-based reasoning may assist students' science learning and motivate their science learning interest, are out of the scope of the study and remain to be explored in future research.

Model-based teaching has recently been advocated in science education (NGSS, 2013; NRC, 2012). In previous studies, students' modeling performance was often investigated without discussion of their learning of science content knowledge or their learning performance and interest in science (Louca et al., 2011; Schwarz et al., 2009; Schwarz et al., 2012; Williams & Clement, 2015). This study contributes to modeling theory by drawing a connection between students' model-based reasoning and their science learning performance and interest, thereby suggesting an implication for current instructional practice: that modeling practice should be integrated into students' science content knowledge in order to enhance students' learning performance and interest. However, seeing that this study focuses only on middle school students, it will be worthwhile for future studies to investigate whether there is also a correlation between high school and college students' modeling practice, science learning performance, and science learning interest.

Students' Epistemology of Models in Science

The analysis of students' views of models in science reveals that these middle school students had a fair to good understanding of models and modeling in most respects, including the sub-factors MR, ET, USM, and the CNM. The exception was the sub-factor ER; students were not sure whether models should ideally be exact replicas of target objects or events. This study also confirms the finding from previous studies that secondary students have a better understanding of the process of modeling than of the nature and purpose of models (Gobert et al., 2011; Grünkorn et al., 2014; Krell et al., 2014; Treagust et al., 2002).

As noted, most previous research has indicated that middle school and high school students tend to have a narrow view of the nature of scientific models, viewing them as physical copies of target objects (Grosslight et al., 1991; Gobert et al., 2011; Treagust et al., 2002).The ninth-grade students in this study achieved better mean scores on the ER section than the secondary students in those previous studies, yet their responses showed that they were still not sure about this aspect of models. By examining their scores according to different sub-factors, this study shows that even though these students agreed that models should be generative tools for predicting and explaining the corresponding events and that the models should change as our understanding does, the students were still not sure whether the model was an exact replica of reality or not. This result may lead to future studies on the problem of students' learning of scientific models and modeling in the classroom, and the reasons why they would get a better understanding of most aspects of the nature of models but not the specific point that the purpose of the model is not to copy the appearance of target objects.

There is a limitation to this study that should be acknowledged here, related to the adoption of the decontextualized SUMS survey. Researchers have argued that epistemic belief is sensitive to context: decontextualized responses may not represent students' understanding in contextualized settings, and students' epistemological responses may differ across contexts (Ford, 2008; Krell et al., 2015; Sandoval, 2015). There have been studies on students' understanding of models and modeling in context, involving comparison of different models for scientific phenomena (Chittleborough, Treagust, Mamiala, & Mocerino, 2005; Krell et al., 2014), different scientific disciplines (Krell et al., 2015), and different forms of representation (Al-Balushi, 2011; Pluta, Chinn, & Duncan, 2011). These results provide various insights into scientific models in particular contexts; in the present study, in contrast, we intended to study students' understanding on neutral ground by eliciting student beliefs in a decontextualized survey, which will help us achieve a better general understanding of students' epistemological beliefs regarding scientific models.

By investigating the relationships between students' views of models in science and their science learning performance, science learning interest, and actual self-developed models, this study found that students who have the best science learning interest have better understanding of MR, ET, USM, and CNM, but not ER. A similar finding was acquired for students' science learning performance, except that students who had the best science learning performance had a more naïve understanding of ER, contrary to the common expectation.

A similar relationship between science learning performance and students' epistemological understanding of scientific models has been found in some recent studies in biology, chemistry, and earth science (Gobert et al., 2011; Krell et al., 2014; Park, 2013), in which the researchers investigated and identified positive relationships between students' scientific conceptions and their perception of scientific models. However, Gobert et al. (2011) found contrary evidence that there is no significant relationship between students' understanding of science and their content knowledge in physics. Researchers have argued that students' understanding of the nature of models is different across science domains (Gobert et al., 2011; Krell et al., 2015). Nevertheless, it remains unexplored why students in Gobert et al.'s (2011) study with more sophisticated understanding of models did not learn better in physics, since physics knowledge is considered to involve building models so as to understand the world. It requires future study to investigate why students do not need to acquire better understanding of models in order to better learn content knowledge in physics. Is this gap because only certain types of physics learning require understanding of models and modeling, or because how physics is learned and taught is different from how it is practiced by physicists?

Nevertheless, this study contributes to the discovery of the adverse relationship between students' science learning performance and their understanding of the relationship between models and their target events. Students who claim to have the best science learning performance may have a stronger naïve understanding of models, seeing them as exact replicas of target objects. This unexpected finding may emerge from the way science content is taught in these students' schools, which may not reflect how scientists perceive the epistemological understanding of scientific models. The difficulty of improving students' understanding of ER has also been noted by researchers (Cheng et al., 2014; Gobert et al., 2011), who have found no significant enhancement of students' understanding of ER as a result of explicit instruction in modeling. This finding suggests the teaching implication that the ontological distinction and sophisticated relationships between models and the target events should be taught and emphasized explicitly in the curriculum, when students learn modeling and understanding of scientific models. These issues require further study with a focus on lesson design and curriculum and an eye to how to improve students' ER in model-based teaching.

With regard to the relationship between students' views of the nature of models and their self-developed models, this study discovered that students who could develop microscopic models, and especially those who could develop coherent microscopic models, had a better understanding of MR, ET, and USM than did students who developed models at the observational level. Nevertheless, this study did not find any statistical evidence that the sub-factors of ER and CNM were associated with students' model development. It has been argued that there is no empirical evidence showing that students' understanding of models is related to their modeling practice (Krell et al., 2015; Louca & Zacharia, 2012). This study contributes to providing empirical evidence in this point, allowing it to identify positive relationships between students' ability to develop models and certain aspects of their views of scientific models.

Nevertheless, based on the finding that most participants in this study were only able to construct models at the observational level, there is a limitation to our ability to generalize the positive relationship between students' understanding of scientific models and their modeling practice, a situation that leads to our recommendation for future research on the relationship between these two aspects, from two particular perspectives. First is to measure students' modeling performance across topics they are familiar with and those they are unfamiliar with—addressing a limitation of this study, which only considered modeling performance on unfamiliar and abstract topics. Sandoval (2015) has argued that students' epistemological responses may vary in different contexts according to whether contexts are familiar or abstract. Hence, it is essential to investigate the relationships between students' modeling performance across contexts in relation to their general understanding of scientific models. The second key area is to explore other possible factors which might explain the gap between students' understanding of scientific models and their modeling performance. Researchers have indicated that issues exist for the internalization of declarative knowledge about science into actual practice of science (Ford, 2008) or issues related to personal epistemic goals (Sandoval, 2015) that might influence the interaction between students' understanding of scientific models and their modeling performance.

Current modeling curriculum, in which epistemological understanding of scientific models is implicitly taught through modeling activities, assists students to generate, evaluate, revise, and apply their models (Bamberger & Davis, 2013; Gobert et al., 2011; Schwarz et al., 2012; Williams & Clement, 2015). The findings of the current study suggest the instructional implication that to enhance students' capability to develop scientific models and to improve their moldering processes, views of scientific models should be explicitly addressed in the curriculum, especially in terms of the aspects of MR, ET, and USM. Science activities should be designed to connect students' understanding of scientific models with their modeling practice. On the other hand, seeing that the current study focuses only on students' ability in model development, without inspecting students' ability in model evaluation, revision, or application, future research should be encouraged to explore the relationship between students' understanding of scientific models and their capabilities in other aspects of the modeling process.

Disclosure statement

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