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Investigating the Relationship Between Views of Scientific Models and Modeling Practice

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Abstract
Understanding scientific models and practicing scientific modeling have been emphasized and advocated in science learning. Although teachers have been perceived as shaping their students' understanding of the nature of science, they have been recognized for their lack of understanding of scientific models. This study explores middle school science teachers' and ninth-grade students' performance in terms of their understanding of scientific models and their construction and evaluation of these models. The study participants comprised 95 science teachers and 608 ninth-grade students. To investigate the students' understanding of scientific models, they were asked to fill out a Students' Understanding of Models in Science survey. To explore the students' model construction and evaluation, they were asked to explain three different magnetic phenomena and to provide the criteria they used to evaluate the scientific models. The results show that the teachers' performance on these three aspects was significantly better than that of the students. However, this study indicated that teachers have similar problems as students in terms of understanding theoretical representations of scientific models and practicing model construction. Moreover, those teachers who had a better understanding that scientific models are not the replica of target events could develop higher levels of models while students with more understanding that scientific models are the replica of target events were able to develop higher levels of models. The findings of the study contribute to a better understanding of the gap between teachers and students, which will be crucial for designing a better modeling-based curriculum.

Keywords Modeling practice · Views of scientific models · Construction of models · Model evaluation criteria · Middle school students · Science teachers

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The understanding of scientific models and the practice of scientific modeling have been emphasized and advocated in science teaching internationally (Gilbert and Justi 2016; Krell and Krüger 2016; Louca and Zacharia 2012; Ministry of Education of Taiwan 2016; Next Generation Science Standards [NGSS] Lead States 2013; Taber 2013). Recently, researchers have identified a positive relationship among students' understanding of scientific models and modeling practice, science content knowledge, learning performance, and students' interest in learning (Cheng and Lin 2015; Gobert et al. 2011; Krell et al. 2014).

The modeling-based curriculum has been designed to enhance students' understanding of scientific models or their modeling practice, including students' own model development and employment, which extends beyond the use of existing models (Cheng and Brown 2015; Cheng et al. 2014; Gilbert and Justi 2016; Louca and Zacharia 2012; Schwarz et al. 2009). Although teachers have been perceived as shaping their students' understanding of the nature of science (Kang et al. 2005), teachers' lack of understanding of scientific models has been recognized (Grosslight et al. 1991; Justi and Gilbert 2002; Van Driel and Verloop 1999). Moreover, few studies have investigated teachers' practical abilities in modeling or examined the relationship between teachers' and students' understanding of scientific models and the practice of modeling, to better address the problems of integrating these modeling-based curricula in actual science classrooms rather than in research settings.

Therefore, this study examines the relationship between students' and teachers' understanding of scientific models and the practice of modeling (model development and evaluation) to make suggestions for teacher training and modeling-based curricula.

Theoretical Background

Teachers' and Students' Understanding of Scientific Models

The views of teaching and learning with models and modeling have been drawn from the philosophy of science, which includes the representation of systems or ideas through the utilization of such models (Gouvea and Passmore 2017; Mahr 2011; Passmore et al. 2014). Models have been perceived as epistemic tools for making sense of the world through inquiry, not as mere knowledge representation of the world or existing ideas. In other words, researchers have argued that the representation of the structure or understanding of target events is insufficient to capture the full scope of the function of models (Gouvea and Passmore 2017; Passmore et al. 2014).

Furthermore, models have often been perceived as context-dependent and contingent on the purpose and the scope of the questions being posed. In order to explain how and why something happens, which aspects are to be explained, and how much detail is needed, different modelers have differing views for satisfying explanation and prediction (Gouvea and Passmore 2017; Passmore et al. 2014).

In practice, Schwartz and Lederman's (2008) empirical studies have found that scientists have differing views about the nature of science itself. Scientists' viewpoints are more tied to their individual research contexts and experiences and may not be aligned with the views for current scientific literacy.

Accordingly, in existing science education research, scientific models have been defined as epistemic tools that provide a consistent thinking structure within a field of study. These models simplify the abstract concepts of scientific phenomena to explain their underlying mechanism or interaction and also to predict unknown phenomena (Grünkorn et al. 2014; Krell et al. 2014; Oh and Oh 2011; Schwarz et al. 2009).

Although the understanding of scientific models has been illustrated slightly differently across the body of research literature on the topic, this understanding can generally be perceived in terms of three dimensions: the nature of models, the purpose of models, and the modeling process. The nature of models involves ontological beliefs about the relationship between scientific models and the target events. The purpose of models reflects different functions of scientific models, including their use as a research tool in several ways: for explaining, predicting, or visualizing target events; as a reasoning tool for developing and testing ideas; or as a communication tool for expressing ideas. The process of scientific modeling involves the constant development, examination, revision, and possible replacement of models (Cheng and Brown 2015; Krell et al. 2014; Schwarz et al. 2009). Consequently, the nature of models could be perceived as the constitution of scientific models. The purpose of models, and the process of modeling, can thus be seen as the utilization of models as epistemic tools through the inquiry process.

To diminish the gap between how students learn science and how scientists actually practice science, the teaching of science emphasizes the practice of scientific modeling (Gilbert 2008; National Research Council [NRC] 2007; 2012; NGSS 2013). However, some studies have found that students may not fully understand scientific models, perceiving them as simply replicating the phenomena the models explain, instead of as representing the abstraction of ideas for conducting scientific inquiry as scientists intend (Gobert et al. 2011; Grünkorn et al. 2014; Krell et al. 2014). Kang et al. (2005) argued that the problem underlying students' understanding of scientific models is that they are presented with information that reflects only the visual or observational aspects of scientific phenomena. Thus, students tend to perceive scientific models as mere functional replicas of these original phenomena, instead of as theoretical representations for exploring observed phenomena.

To address this issue, Schwarz and White (2005) suggested that students need more modeling practice to develop a deeper understanding of the intent of the models. During such practice, it would be desirable for students to comprehend the scientific rationale underlying the process. To achieve this, in previous studies, we showed that explicitly teaching how modeling is practiced by actual scientists encourages students to reflect on their own models (Cheng and Brown 2015; Cheng and Lin 2015; Cheng, et al 2014; Cheng, et al 2017).

However, just as students often fail to develop an appropriate understanding of scientific models, teachers' understanding may also be similarly limited (Justi and Gilbert 2002; Van Driel and Verloop 1999). Studies have revealed that teachers do not have a clear understanding of the nature of modeling, nor the multiple representations of scientific models (Justi and Gilbert 2002). In practice, most teachers focus on the usefulness of models to communicate science content, instead of discussing the fundamental nature of scientific modeling (Henze et al. 2007; Justi and Gilbert 2002; Van Driel and Verloop 2002). Similar to most students, many teachers believe that scientific models should be completely accurate demonstrations of phenomena—or as simplified representations of target events (Krell and Krüger 2016; Lin 2014; Van Driel and Verloop 1999). Teachers are also influenced by their own fields of expertise, which may result in a vulnerability of over-emphasizing specific types of models within a teacher's particular area of competence (Schwarz et al. 2009; Windschitl and Thompson 2006).

In light of some teachers' inadequate understanding of scientific models, when teaching a modeling-based curriculum, these same teachers may face challenges in designing (or delivering) content that reflects an appropriate understanding of scientific modeling. Thus, students may be left with an inappropriate or incomplete understanding of scientific modeling. Therefore, this study explores the degree to which scientific models are understood by middle school science students and teachers, identifies the gap between the two, and makes recommendations for how an effective modeling-based curriculum may be further developed.

Students' and Teachers' Construction of Models

In the modeling process, learners develop models based on existing mental models, gradually reevaluating and revising them as their understanding of scientific models develops (Cheng and Brown 2010, 2015; Davis et al. 2008; Gilbert and Boulter 1998). In this way, learners utilize their own internalized models for making sense. During modeling curricula, students were often asked to articulate their understanding of scientific phenomena to better explain and predict them (Davis et al. 2008; Schwarz et al. 2009). Ultimately, the product and the process of modeling both play essential roles for students' learning about science.

Recent contributions to the pedagogy of science advocate that learners should construct and use models in a way similar to the way scientists actually use them (Gilbert 2008; NRC 2007; Krell et al. 2012; NGSS 2013). However, recent research reveals that middle school students are not performing well in terms of constructing and using models. Students focus on observational similarities between models and target events, but few students can effectively employ abstract models to represent their ideas, or to coherently explain the mechanisms underlying target events (Cheng and Lin 2015; Cheng et al. 2017; Guisasola et al. 2004; Voutsina and Ravanis 2012).

In contrast, although teachers may guide students in developing models, few studies have investigated the ability of middle school teachers to construct and employ models. Hence, this gap between students' and teachers' understanding of models has not been identified until now. This study aims to address this rift, exploring how ninth-grade students and middle school teachers approach the construction and utilization of models, and then examining the dissimilarities between the two groups. The study also investigates the extent to which students' and teachers' understanding of scientific models is associated with the construction of their respective models.

Teachers' and Students' Evaluations of Models

Evaluating models, an essential element in the process of constructing models, reflects the degree to which individuals understand the nature and practice of science (Bayir et al. 2014; Pluta et al. 2011). Due to the contextual nature of scientific reasoning, the modeling process is influenced by modelers' epistemological criteria (such as predictive precision or explanatory power): modelers build different models depending on their different epistemic aims. In short, types of model, or modeling processes, are dependent on the questions that need to be answered and the best tool for the particular context (Passmore et al. 2014).

To improve the validity and accuracy of scientific models, scientists often evaluate them according to criteria related to the nature of science, such as the explanatory and predictive functions of models (Kuhn 1977; Van Der Valk et al. 2007). On the other hand, students evaluate models differently, often based on personal criteria (rather than scientific). Therefore, students usually have problems developing and revising their models to approximate the scientific modeling process (Chang and Chang 2013; Cheng and Brown 2010, 2015). Using scientific (rather than personal) criteria for evaluating models would likely provide students with clear learning goals while assisting them in developing and modifying their own models. As students reflect on the criteria for evaluating scientific models, they learn to control their own modeling process more effectively, thereby promoting better model-based reasoning and a better understanding of scientific models overall (Cheng and Brown 2015; Sins et al. 2009; Pluta et al. 2011).

Criteria for evaluating models for both scientists and students can be classified into three aspects: the nature of scientific models, the communicative aspect of models, and superficial understanding of models.

Criteria for evaluating models, which examine the nature and purpose of scientific models, are related to the nature of science. For example, scientific models are usually developed on the basis of existing theories and evidence (Chinn and Brewer 2001; Chinn et al. 2010; Kuhn 1977), or based on the intended purpose of the scientific model to explain observed scientific phenomena or to predict unknown phenomena (Giere 1988; Mayr 1982; Schwarz and White 2005). Kuhn (1977) also pointed out other important criteria for evaluating scientific models: accuracy, explanatory scope, parsimony, internal or external consistency, and fruitfulness. To improve scientific models, they must thus be modified on the basis of these criteria.

The criteria for evaluating models, which emphasize their expression or representation of models, are related to the communicative aspects of modeling. Scientific models can be employed as tools for conveying and communicating understanding or knowledge of the process of scientific reasoning (Harrison and Treagust 2000). The evaluation of the expression of a model usually contains model constitution as exemplified in text, figures, and symbols; evaluation also involves communicative descriptions, such as clarity, sequence, and organization to better communicate understanding and reasoning and to enhance a model's ability to explain or predict phenomena. Finally, the criteria for evaluating models, especially those related to empirical and observational features of target events, tend to focus on the appearance aspects of models, asking whether the manifestation of the model is similar to the original phenomena. These particular criteria only serve to emphasize a superficial understanding of models (Kuhn 1977; Pluta et al. 2011; Schwarz et al. 2009).

Until now, few researchers have examined students' assessments of models in relation to that of teachers. Research to date has identified students' limited ability to assess models (Cheng and Brown 2015; Pluta et al. 2011). The criteria students proposed emphasize communicative criteria (e.g., clarification and figures) or superficial criteria (e.g., similarities), rather than the nature of scientific inquiry (e.g., explanations and evidence). As stated above, teachers have a great influence on what and how students learn about models and modeling, yet few studies have investigated teachers' own abilities to evaluate models. Therefore, to better identify this differential in understanding of models and modeling between teachers and students, this study compares ninth-grade students' ability with that of science teachers' to assess scientific models.

In addition, scholars have contended that the understanding of scientific models is an essential factor that influences students' modeling performance (Nicolaou and Constantinou 2014; Schwarz et al. 2012). However, researchers have also argued that there is no empirical evidence to support this hypothesis (Krell et al. 2015). Accordingly, this study not only investigates students' and teachers' relative understanding, construction, and evaluation of scientific models but also explores the relationship between their understanding of scientific models and modeling performance.

Research Questions

Three primary research questions guide the present study. (a) How do teachers and students perform in their understanding of scientific models and their ability to construct and to evaluate models? (b) What are the differences between teachers' and students' performance in their understanding of scientific models and their construction and evaluation of models? (c) Is there any correlation between students' and teachers' performances in understanding scientific models or in constructing or evaluating them?

Research Methodology

We recruited 95 middle school science teachers and 608 ninth-grade students from schools throughout central Taiwan. Several of the teachers did, at some point, teach the student participants. However, no members in either group could be identified, because both teachers and students participated anonymously. Each participant consented to the study before filling out their questionnaires. The middle school teachers had teaching certificates and teaching experience. The ninth-grade students were recruited from both urban and rural schools. They were selected from standard classes and had not received special placement based on academic performance. Prior to our study, these participatory students had not learned scientific models of magnetism, such as domain or atomic models of magnetism, in their science curriculum. Three instruments were used in this study.

Understanding of Scientific Models

The first instrument, the Students' Understanding of Models in Science (SUMS) survey (Treagust et al. 2002), measured both the students' and the teachers' understanding of models. This survey has five dimensions: models as multiple representations (MR), models as exact replicas (ER), models as explanatory tools (ET), the uses of scientific models (USM), and the changing nature of models (CNM). There are eight items in the MR dimension, which investigates the students' views on using multiple models to represent different perspectives on the same target events. There are eight items in the ER dimension, which examines the students' views on using models as idea-based representations of target events. There are five items in the ET dimension, which explores the students' perceptions of models as explanatory and communicative tools. There are three items in the USM dimension, which inspect the students' perceptions of models as research tools used to construct theories and predict scientific phenomena. There are three items in the CNM dimension, which examines the students' perceptions of the models as being revised or replaced according to new theories, findings, or beliefs.

Students' responses are based on a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5), so the mean scores of these five dimensions are between 1 and 5. For each dimension except ER, a higher score represents a better understanding of the scientific models. In the case of ER, a lower score represents a better understanding. The mean scores of the students' responses on the five dimensions represent their degree of understanding in these five different dimensions. In the study done by Treagust et al. (2002), the reliability measures for the individual dimensions ranged from 0.71 to 0.84. In our present study, the reliability measures for these dimensions ranged from 0.78 to 0.90 for students and from 0.71 to 0.82 for teachers.

The Construction of Magnetic Models

The second instrument examined the students' and teachers' ability to construct explanatory models for illustrating the unobservable and underlying mechanisms behind observable magnetic phenomena. To explore whether the participants could construct explanatory scientific models, this study adopted an instrument designed by Cheng and Brown (2015). Participants were encouraged to develop and draw their own models involving hidden and non-observable underlying mechanisms to explain three different magnetic phenomena rather than articulate the observable patterns of events. In these three questions, they were asked to identify and illustrate the parts of a bar magnet which can attract iron nails, to clarify the reason why general iron nails do not attract other iron nails, and to explain the reason why iron nails attract other iron nails after being attached to the bar magnet.

The purpose of this survey was to examine whether students could self-construct microscopic models without the assistance of their teachers and coherently explain three different magnetic phenomena. The coding scheme for this instrument used three levels and is illustrated in Table 1 (Level 1: observed phenomena or imaginary models in a macroscopic view, Level 2: microscopic models explained one magnetic phenomenon but did not explain the two other magnetic phenomena, Level 3: coherent and microscopic models explained two or three magnetic phenomena).

This study adopted the atomic magnetic domain model as a reference model to evaluate the student and teacher responses. The atomic magnetic domain model uses the interactions among invisible microscopic elements that lead to occurrences of macroscopic phenomena. The microscopic interpretation model, not the macroscopic observations, was the focus of explaining underlying mechanism. For the initial coding, the consensus between the two researchers was 99.4% for teachers and 95.2% for students. All inconsistencies were resolved after discussion.

The Evaluation of Scientific Models

The third instrument asked students and teachers to propose appropriate criteria for evaluating the scientific models they proposed. It first asked participants to provide examples of scientific

Table 1 Coding for the interpretation of models constructed for magnetic phenomena

Level	Level definition	Examples
Level 1	Answers described only observed phenomena or imaginary models in a macroscopic view.	For example, the ends of magnets attract nails (direct observation); special materials transmit magnetism (macroscopic imagination).
Level 2	Answers used microscopic models to explain one magnetic phenomenon but did not explain the two other magnetic phenomena.	For example, participants explained why the nails already attracted by magnets attracted other nails by using the arrangement of microscopic elements but did not explain the two other problems using the same model.
Level 3	Answers employed coherent and microscopic models to explain two or three magnetic phenomena.	For example, participants explained two or three magnetic phenomena by applying different arrangements of microscopic material inside magnets and nails, such as positive and negative charge or small magnets.

models and then to list criteria they could use to evaluate whether these proposed models are good scientific models.

The responses were categorized and analyzed according to Pluta et al.' (2011) criteria for evaluating models. Criteria related to the practice of science, such as the explanatory and predictive functions of the models, were categorized as Level 3 (descriptions of the nature of scientific models). Criteria that had no effect on the accuracy of the scientific models but had auxiliary functions in the models, such as the expression and representation of models, were classified as Level 2 (communicative aspects of models). Finally, criteria that were vague or simply incorrect were classified as Level 1 (superficial understanding of models). The coding details are provided in Table 2; for the initial coding, the consensus between the two researchers was 98.7% for teachers and 99.4% for students. Again, all inconsistencies were resolved after discussion.

Data Analysis

The purpose of this study was to explore middle school teachers' and ninth graders' understanding of scientific models and the teachers' and students' abilities to construct and evaluate models. The quantitative and qualitative data collected from the participants' responses were analyzed quantitatively to answer the three research questions.

To answer the first research question, about teachers' and students' understanding of scientific models and constructing and evaluating models, descriptive statistics were employed to investigate the distribution of the respondents' performance in these three aspects. To answer the second research question, about the differences between teachers and students in terms of each aspect, independent sample *t* tests were used to investigate whether there were differences in the averages of these three aspects. Chi-square tests were also used to examine whether there were differences in the distribution within the two groups at each level in terms of each aspect.

Table 2 Coding for interpretation of criteria for evaluating models

Level	Level Definition	Examples
Level 1	Responses demonstrate only a superficial understanding of model evaluation and do not mention the communicative elements of models or the aspects of modeling related to the nature of science.	For example: "Because it is three dimensional, it is a good scientific explanation model." This evaluation criterion addresses only the appearance of scientific observation.
Level 2	Responses include the communicative aspect of models (and may have included superficial understanding of models) but do not mention the criteria related to the nature of science.	For example: "It can be used to express scientific ideas through real objects." According to the evaluation criteria, "expressing scientific ideas" represents the communicative aspect of models, and "real objects" reflect the superficial aspect.
Level 3	Reponses include criteria related to the nature of science (and may also include communicative aspects of models, as well as superficial understanding).	For example: "Equipped with functions that can express or explain the scientific phenomenon." The evaluation criteria are interpreted as including "explanation" as related to the nature of science and "expressing" as reflecting the communicative aspect of models.

To answer the third research question and examine the relationship between students' and teachers' performances in their understanding of scientific models and their ability to construct and evaluate them, Pearson's correlation was used to determine whether there was a connection between the average scores for constructing models and understanding models, between the average scores for evaluating models and understanding models, and between the average scores for constructing models and evaluating models.

Results

According to the descriptive statistics shown in Table 3 and the independent sample *t* tests, teachers scored significantly higher than students in all dimensions related to understanding scientific models based on a Likert scale ranging from 1 to 5. In addition, the standard deviation of each dimension for the teachers was smaller than that of the students. Therefore, the teachers had a more sophisticated understanding of scientific models in all categories except ER, in which higher scores depicted a lower understanding of models as theoretical representations. The standardized mean difference effect size for MR is .38, .33 for ER, .56 for ET, .44 for USM, and .43 for CNM. According to Cohen's (1988) definition of small, medium, and large effect sizes as $d = .2$, .5, and .8, respectively, the effect size of these five dimensions is considered to be between the small and medium ranges. It reveals that teachers scored significantly better than students in their overall understanding of scientific models, except in the case of ER. These results may have been influenced by the large difference of the sample sizes between students and teachers.

Table 4 reveals that the abilities of the teachers to construct models for magnetic phenomena were more sophisticated than those of the students. Although 62.1% of the teachers scored at the lowest level in constructing models (Level 1: observed phenomena or imaginary models in a macroscopic view), 33.7% was able to engage with the most sophisticated models (Level 3: coherent and microscopic models to explain two or three magnetic phenomena). Meanwhile, the majority of the students (96.5%) used observational and macroscopic models to explain the magnetic phenomenon, while very few students (2%) could do so with microscopic and coherent models.

Table 3 Descriptive statistics concerning the understanding of scientific models and independent sample *t* test of the two groups

Category	Participants	Average scores	Standard deviation	t
MR	Teachers	4.16	0.50	3.44**
	Students	3.96	0.53	
ER	Teachers	3.51	0.54	2.92**
	Students	3.32	0.59	
ET	Teachers	4.20	0.56	5.38**
	Students	3.87	0.59	
USM	Teachers	4.23	0.63	3.99**
	Students	3.93	0.69	
CNM	Teachers	4.38	0.69	3.87**
	Students	4.06	0.75	

**$p < .01$

A chi-square analysis was conducted to investigate whether there was a statistically significant difference between the modeling abilities of teachers and students at each of the three levels. These results are presented in Table 4. In the case of modeling ability, the chi-square analysis results show that the percentage of middle school students at Level 1 was significantly higher than that of teachers, while the percentage of teachers at Level 3 was significantly higher than that of students.

In Table 5, the evaluations of the models done by teachers were more sophisticated than those done by students. The majority (75.8%) of the teachers' evaluations focused on the nature of scientific models, while only a small percentage (14.7%) focused on the communicative aspects of models. Very few (9.5%) of the teachers only paid attention to the superficial criteria for evaluating models. This result illustrates that most teachers understood the importance of the nature of the model and did not pay attention to superficial aspects. In contrast to this, 42.5% of the students paid attention to criteria related to the nature of science, 36.5% paid attention to the superficial characteristics of the models, and 20.9% focused on the models' communicative aspects. This indicates that the students have a greater variety of understanding of the proper way to evaluate scientific models.

To show the difference between the percentages of teachers and students at each level, a chi-square analysis was used to investigate the model-evaluation ability of both groups of participants. This distribution is shown in Table 5. The results of the chi-square analysis show that the teachers were able to better evaluate models than the students. The percentage of students who were able to understand models at the most superficial level was statistically significantly higher than that of the teachers. However, the percentage of teachers who were able to understand models at their most sophisticated level was statistically significantly higher than that of the students. There was no statistically significant difference between the levels of understanding for students and teachers at the middle level, which emphasized the communicative aspects of models.

Table 6 lists the results regarding the Pearson correlations (for both teacher and student samples) between understanding of scientific models and constructing models of magnetism. Due to a large difference between the sample size of the teachers and that of the students, the correlations of .12 and .09 are statistically significant for the student sample, but the correlation of .19 is not statistically significant for the teacher sample. According to Cohen's (1988) benchmarks for classifying correlations in the social sciences, a small effect size is .1–.23, a medium effect size is .24–.36, and a large effect size is .37 and above. In this study, only the correlation between teachers' understanding of ER and their construction of models for explaining magnetic phenomena is medium in size. The rest of the correlations are relatively small and perhaps negligible.

Table 4 Chi-square analysis of teachers' and students' modeling ability for explaining magnetic phenomena

Modeling ability level	Teachers	Students			χ^2	p	Comparison (percentage %)
	n	%	N	%			
Level 1	59	62.1	587	96.5	139.52	0.00	Students > teachers
Level 2	4	4.2	9	1.5			
Level 3	32	33.7	12	2.0			Teachers > Students
Total	95	100.0	608	100.0			

Table 5 Chi-square analysis of teachers' and students' ability to evaluate the models

Evaluation ability level	Teachers		Students		χ^2	*p*	Orientation percentage comparison
	n	%	*n*	%			
Level 1	9	9.5	222	36.5	39.06	0.00	Students > Teachers
Level 2	14	14.7	127	20.9			
Level 3	72	75.8	259	42.6			Teachers > Students
Total	95	100.0	608	100.0			

In Table 6, teachers' measured ability to construct models for explaining magnetic phenomena and the ER measure of the teachers' understanding of models (interpreting models as things that replicate real phenomena) reveal a statistically significant negative correlation. The better a teacher understood that models are not real copies of scientific models, the better models they were able to develop. Although the correlations between students' construction of models for explaining magnetic phenomena and their understanding of MR and ER are statistically significant and positive, these correlations should be disregarded because of their small effect sizes.

Table 7 demonstrates a comparison of the evaluations of the models with the SUMS scores. Due to the large difference in sample sizes, correlations of .10, .11, .12, and .17 are statistically significant for the student sample, but correlations of .14 and .19 are not statistically significant for the teacher sample. According to Cohen's guideline (Cohen 1988), in this study, only the correlation between teachers' understanding of CNM and their evaluation of the models is medium in size. The rest of the correlations are relatively small and perhaps negligible. The results reveal that the better teachers understood the changing nature of models, the better they were able to refer to the nature of science to evaluate scientific models.

Our results also reveal a statistically significant positive correlation in regard to students' and teachers' ability to construct and evaluate models. The correlation coefficients are .21 ($p < .05$) and .11 ($p < .01$), respectively. However, according to Cohen's (1988) guideline, the correlation between good model construction and good model evaluation is weak and could be negligible.

Discussion

This study's results firstly identified similar problems among teachers and students in regard to their understanding of the theoretical representation of models and secondly unveiled the gap between the two groups in their abilities to construct and evaluate models in order to gather insights into teacher training and the design of a modeling-based curriculum. However, this

Table 6 Pearson correlations between understanding of models and construction of models for both teachers and students

	MR	ER	ET	USM	CNM
Teachers' construction of models	− .19	− .26*	− .05	− .11	− .01
Students' construction of models	.12**	.09*	.07	.07	.04

*$p < .05$. **$p < .01$

Table 7 Pearson correlations between teachers' and students' understanding of models and evaluations of the models

	MR	ER	ET	USM	CNM
Teachers' evaluations of the models	.07	− .07	.19	.14	.26*
Students' evaluations of the models	.17**	− .01	.10*	.12**	.11**

*$p < .05$. **$p < .01$

study poses important limitations, as it does not attempt to draw a causal relationship between how these teachers' approaches toward modeling might affect their students' understanding and performance in modeling; rather, this study presents an overall picture of students' and teachers' collective understanding of scientific models and the practice of scientific modeling.

Issues in Understanding Scientific Models

The results indicate that, in most aspects, teachers' performance was statistically significantly better than that of students, the exception being the understanding that models do not replicate phenomena precisely. Previous researchers have demonstrated that students experience issues with understanding scientific models, especially in that models do not precisely replicate real phenomena (Cheng and Lin 2015; Park 2013; Treagust et al. 2002).

However, previous studies have shown that teachers also possess a limited understanding of scientific models and may regard models as either replicas or simplified representations of original ideas (Danusso et al. 2010; Justi and Gilbert 2002; Krell and Krüger 2016; Lin 2014; Van Driel and Verloop 1999). The present study's results also suggest teachers experience problems similarly as do students in terms of understanding theoretical representations in scientific models, although teachers' understanding of multiple representations, explanatory tools, utilization, and the changing nature of scientific models may be better than that of students.

Issues in Model Construction

In regard to constructing models, teachers are statistically significantly more capable than students of using an abstract, hypothesized microscopic model to coherently explain scientific events because students predominantly employed observed or macroscopic models in descriptions. The difficulties middle school students experience in constructing models have been previously observed (Cheng and Lin 2015; Guisasola et al. 2004; Voutsina and Ravanis 2012). However, this study additionally reveals that more than half of the teachers explained the unseen mechanisms of magnetism using observed or macroscopic models, thus indicating that teachers may also experience difficulties building abstract theoretical models.

In terms of the correlation between understanding and constructing scientific models, we found that teachers who better understood that scientific models are unlikely simple replications of target events developed higher-level models, while the effect size of the correlation for students is relatively small and has no practical importance. This may reflect an issue in the way teachers present scientific models to their students as theoretical representations, but these modeling processes have not been learned or practiced by students. Alternatively, students may have recognized scientific models as representing abstract ideas while remaining unable to develop abstract theoretical models themselves.

Issues in Evaluating Models

Previous studies have indicated that novice learning usually focuses more on communicative and superficial criteria than on the nature of science (Cheng and Brown 2015; Pluta et al. 2011). The present study found that teachers possessed more scientific criteria for evaluating models, whereas students possessed more naïve views of evaluating models; however, students were nevertheless capable of proposing some scientific model evaluation criteria. The evaluation of models has been found to reflect an individual's understanding of science (Bayir et al. 2014; Pluta et al. 2011). Similarly, in the present study, the teachers who demonstrated a better understanding of the changing nature of models were more likely to provide higher-level criteria for evaluating scientific models, but the effect size of this correlation for students is relatively small and has no practical importance.

In the modeling-based curriculum, previous studies have scaffolded students to reflect on their models with self-generated criteria or scientific model evaluation criteria to enhance their model development (Chang and Chang 2013; Cheng and Brown 2015; Mendonça and Justi 2014; Schwarz et al. 2009; Schwarz and White 2005). The present study demonstrated a small, positive relationship between evaluating models and constructing models in the student and teacher groups. This weak correlation suggests that enhancing students' model evaluation may be one of the important steps toward improving students' model construction; nevertheless, other important steps require further consideration.

The Limitations of the Study

One limitation of the study is that the instruments may not actually measure individual ability due to the context of the instruments. The instrument of understanding of models in science does not consider the relationship between context and epistemological views. Research has shown that students have different understandings of scientific models within different scientific disciplines and different contexts and depending on whether tasks are decontextualized or contextualized (Gogolin and Krüger 2018; Krell et al. 2015; Krell et al. 2012). Therefore, when participants in this study revealed their understandings of models and their model evaluation criteria through a decontextualized survey, their responses may have been limited by specific models in particular contexts that they were considering when they responded. While this decontextualized design offers a broad picture of students' and teachers' views of scientific models, it may neglect the different views between different contexts.

Moreover, regarding model evaluation, participants were asked to provide examples of scientific models and list the criteria they used to evaluate whether these models are effective. However, the ability to list evaluation criteria is not equitable to actually evaluate scientific models during the modeling process. Hence, future studies should examine participants' model evaluation criteria and processes during their modeling practice.

Another limitation is that most of the correlations between students' understanding of scientific models and their model construction and model evaluation is small, representing no practical importance in these relations.

Implications for Teacher Training and a Modeling-Based Curriculum

For the understanding of scientific models, this study revealed the surprising finding that teachers do not necessarily make more sophisticated interpretations than students. This result is illustrated in the ER dimension of Table 3, which indicates teachers may not possess a better understanding of the abstract representations of models. This interesting finding might be explained in relation to previous research showing that most teachers emphasize how scientific models should be employed to teach learning content rather than to address their relationship with the nature of scientific inquiry (Henze et al. 2007; Justi and Gilbert 2002; Van Driel and Verloop 2002). These teachers, similar to students, might have perceived the teaching models they employ in class as replicating the target events. Gouvea and Passmore (2017) also pointed out that science textbooks and the curriculum depict objects or systems as models without making connections to target phenomena and using them as tools to make sense of the world. The description of events is not linked to explanation and prediction; accordingly, it is likely that teachers and students will perceive scalar representations of objects or events.

It seems that learning more abstract theoretical representations of scientific models than students does not enable teachers to possess a more sophisticated understanding. Accordingly, to enhance their understanding of the nature of scientific models, teachers should practice the modeling process during the teacher training program such that they may gain experience in model development. To make the teaching of a modeling-based curriculum more effective, teachers should become aware of the ways by which models can be employed as abstract theoretical representations, thus allowing that they facilitate the appropriate design of the curriculum and scaffold an appropriate understanding of scientific models.

In regard to constructing models, Table 4 indicates that, even though teachers' abilities to construct models were more sophisticated than those of the students, most teachers still experienced issues developing coherent microscopic models to explain underlying mechanisms of magnetic phenomena. Thus, to improve the models constructed by teachers in teacher training and those constructed by students in a modeling-based curriculum, it is essential that both teachers and students distinguish when and how to develop and employ different types of models. Such types include observable macroscopic models which describe observation (e.g., Ohm's law model to describe the mathematical relationship between voltage, current, and resistance), and unobservable microscopic models which explain underlying mechanisms (e.g., the moving electron models used to explain electric circuits) during teachers' and students' practice of modeling.

In addition, this study's results reveal the disconnect between students' understanding of scientific models and their model construction and evaluation (see Tables 6 and 7). The current modeling-based curriculum tends to focus on either using activities or practicing modeling processes to enhance learners' understanding of scientific models (Danusso et al. 2010; Gilbert and Justi 2016; Krell and Krüger 2016). Nevertheless, Gobert et al. (2011) have verified that engaging in modeling activities may not promote students' understanding of scientific models; rather, the epistemology of scientific models should be explicitly taught within the modeling-based curriculum. Explicitly teaching the epistemology of scientific modeling to help students acquire the rationale underlying the modeling process has been previously studied (Schwarz and White 2005; Snir et al. 2003). Researchers have indicated that presenting the epistemology of scientific models through a modeling-based curriculum may help students not only learn about modeling, but also translate this knowledge into modeling practice (Cheng and Brown 2015; Cheng et al. 2014; Cheng et al. 2017). Nevertheless, further research is required to determine how this epistemology should be taught to more effectively connect learners' understanding and practice of scientific models.

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