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# SCAFFOLDING MIDDLE SCHOOL AND HIGH SCHOOL STUDENTS' MODELING PROCESSES

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**Abstract.** *This research explores how scaffolding students' reflections on scientific modeling criteria influence the students' views on scientific models, development of explanatory models, and understanding of scientific models. This research recruited treatment groups and comparison groups in middle schools and high schools. The treatment groups adopted a modeling curriculum that was intended to help students engage in scientific modeling by developing scientific models of magnetism while considering scientific modeling criteria. The comparison groups used the traditional curriculum, which offers students scientific models of magnetism. The results show that the modeling curriculum enhanced the students' views on scientific models and the students' ability to develop explanatory models of magnetism and modeling criteria. Thus, the findings indicate that the modeling curriculum might serve as a promising tool to facilitate teaching scientific modeling to middle school and high school students, and that the curriculum should be promoted as early as middle school.*

**Keywords:** *scientific modeling, modeling curriculum, nature of models and modeling, model development, model evaluation, magnetism concepts.*

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## Introduction

Engaging students in modeling is essential in current science education. Nevertheless, the means of structuring the modeling process to assist students in reflecting on their scientific thinking and in developing scientific models has been under-investigated (Cheng & Brown, 2015). According to existing surveys (Cheng & Lin, 2015, Gobert et al., 2011; Grünkorn, Upmeier zu Belzen, & Krüger, 2014; Park, 2013; Treagust, Chittleborough, & Mamiala, 2002), we found current middle school and high school students have a naïve understanding of the nature of scientific models and modeling, and the students' model-based reasoning is limited to the observable and fragmented level. Accordingly, the main purpose of the present research is to explore how to enhance middle school and high school students' understanding of scientific models through the practice of scientific modeling.

### *Models and Modeling*

For decades, the essential role of models and modeling has been recognized in scientific thinking and reasoning (Coll & Lajium, 2011; Gilbert, 2004; Nersessian, 2008) and in science education (Coll & Lajium, 2011; Halloun, 2011; NRC, 1996, 2007; NGSS Lead States, 2013). A scientific model is a simplified abstract representation of ideas about the structure and the behavior or the target phenomenon, which allow individuals to develop and examine their explanations for the mechanism underlying scientific phenomenon (Brewer, Chinn, & Samarapungavan, 2000; Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008).

Models are developed through modeling, in which inquirers construct and manipulate explanatory representations, and such modeling is a funda-

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mental process for scientific inquiry (Schwarz & White, 2005). For scientists, modeling is also a process of inquiry in problem solving and a means of developing new models or theories. Nersessian (2008) pointed out that conceptual innovation and change in science involve the process of building, critiquing, and modifying models. These models not only support reasoning but also serve as working devices for reasoning and creating new conceptions for theory building.

### *Model-Based Learning*

In model-based learning, students are involved in a dynamic and recursive process of developing, evaluating, and revising mental models of phenomena (Gobert & Buckey, 2000; Halloun, 2011; Louca, Zacharia, & Constantinou, 2011; Passmore, Stewart, & Cartier, 2009; Schwarz et al., 2009; Stewart, Cartier, & Passmore, 2005; Windschitl et al., 2008). The objective of model-based learning is to help students develop integrated mental models that students can employ in their reasoning (Buckley, 2000).

In model-based learning, there are diverse ways to engage students in the process of model building. In the following, we discuss three approaches to modeling: teacher generation of models, teacher-student co-construction of models, and student generation of models. Researchers use different perspectives to support students' model-based learning.

#### *Teachers Generate Models for Students*

Several researchers have focused on how models should be presented to students (Botzer & Reiner, 2005; Dedes & Ravanis, 2009; Verhoeff, Waarlo, & Boersma, 2008) and how teachers can use strategies, such as analogies or computer simulations, to help students understand the presented models (Baek, Schwarz, Chen, Hokayem, & Zhan, 2011; Xie & Pallant, 2011). This research focuses on teaching models and how these models should be delivered to students or how different kinds of models (such as analogical models or scale models) can help students build and manipulate their mental models.

Harrison and Treagust (2000) recognized the problems of student-generated models which are far from scientific models. They suggested that teachers should select analogies to facilitate the connection between the target model and the base analogy for students. Although teaching models were usually derived from students' existing ideas (Dagher, 1995a; Gilbert, Boulter, & Rutherford, 1998), in these studies the teachers still controlled the product and the process of model building. Teachers usually choose appropriate models and introduce them to students or negotiate the models with students (Dagher, 1995b). In this way, students learn with the models, but without controlling the product and the process of model building, the students do not have ownership of the models as with self-generated models.

#### *Teacher and Student Co-Construct Models*

Rea-Ramirez, Clement, and Nunez-Oviedo (2008) proposed a model co-constructed by students and teachers. During this process, the teacher and the students contribute ideas to build, evaluate, and modify the models. This approach is a compromise between emphasizing teacher-generated models and emphasizing student-generated models. Construction of the model is facilitated to progress from simple initial models that are evaluated and revised to a series of more complex and sophisticated intermediate models, to eventually reach the target models. During the co-construction process, cognitive dissonance is utilized to foster small changes in the models. Analogies are used to build on students' existing knowledge to construct and revise their models (Clement, 2008b; Clement & Steinberg, 2002, 2008; Steinberg, 2008). The co-construction goal focuses on how teachers and students can co-construct models by offering students appropriate analogies and producing cognitive dissonance.

#### *Students Generate Models*

Some researchers are interested in how students generate models. In these studies, model development is facilitated by reading text, interacting with multimedia, or conducting observation and experiments (Acher, Arca, & Sanmarti, 2007; Buckley, 2000; Louca et al., 2011). Students must generate models and regulate reasoning during interaction with materials that are intended to provide the students with pieces of related information. Teachers act only as discussion facilitators without intervening in the students' model construction and guide the students to construct appropriate target models. The results of these studies showed if students are merely offered pieces of information, then only a few students are able to engage in the model-building process or develop scientific models. In Boulter's (2000) study, students were encouraged to construct models in a child-centered questioning discourse. The results showed that the teachers had to guide the students to construct the appropriate models and lead the students' argument in certain ways. Louca et al. (2011) also showed that without teacher support students faced obstacles moving from descriptive models that describe how something happens over time to causal models that describe how an agent affects a physical process.

Accordingly, without designed activities and guided reasoning or discussion, students seem to have problems monitoring their own reasoning and constructing consistent and coherent models. Without guidance, student-generated models are not really similar to scientific models. In order to help students to practice the process of model building and foster their abilities to self-generate scientific models without offering them appropriate analogies or scientific models, or producing their cognitive dissonance, our works focus on how students' can be assisted to self-develop scientific models.

Our previous works have shown that scaffolding students with reflection on the scientific modeling criteria during the students' modeling process assists them to better evaluate and revise their models to become scientific models than reflection on the students' self-generated model evaluation criteria (Cheng & Brown, 2010, 2015). Our curriculum designed for college students with a non-science major about introducing the nature of scientific models and reflection with scientific modeling criteria enhances not only the students' evaluation and revision of their models toward more coherent and sophisticated models but also the students' understanding of scientific models (Cheng et al., 2014).

Nevertheless, whether there is a difference between this innovative curriculum, which scaffolds students' self-generation of models, and the traditional curriculum, which offers students scientific models directly, is unclear. Therefore, this research focused on the adoption of this innovative curriculum in middle school and high school in order to explore whether students' understanding of scientific models, model development, and model evaluation would improve more in comparison to the traditional curriculum. In the present research, the following primary research question is answered:

Does engaging middle school students and high school students in modeling by introducing them to scientific modeling criteria enhance the students' understanding of scientific models, model evaluation criteria, and the development of explanatory models?

**Research Methodology**

In this research, the students who participated in the modeling curriculum were guided through the cycle of model generation, evaluation, and modification to develop a series of progressively more coherent, consistent, and sophisticated explanatory models. The research used the magnetic domain model as a target model for the students. During this process, students reflected on the scientific modeling criteria to help monitor their reasoning during their modeling processes. The innovative curriculum involves a series of inquiry activities for modeling practice, an interactive computer simulation tool to facilitate students' reasoning at the microscopic level, and an introduction to reflection on scientific modeling criteria.

On the other hand, the students who participated in the traditional curriculum were guided to learn the magnetic domain model directly from their instructors without having the opportunity to develop their own models or learn the nature of scientific models and the processes of modeling. Both the modeling curriculum and the traditional curriculum took around three sessions, ranging from 135 minutes to 150 minutes.

The treatment groups (which adopted modeling curriculum) were compared with the comparison group (which adopted the traditional curriculum) in order to inspect whether reflecting on scientific modeling criteria to self-develop models of magnetism would help students have a better understanding of scientific models, develop better models of magnetism, and employ better model evaluation criteria than students who only received scientific models directly from their instructors.

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*Research Design*

*Participants and Instructors*

To evaluate the impact of this modeling curriculum, the classes participating in this research were assigned to either treatment or comparison groups. This research recruited two treatment groups ($n$ = 59) and three comparison groups ($n$ = 92) in middle schools, as well as two treatment groups ($n$ = 40) and two comparison groups ($n$ = 33) in high schools. In the middle school and high school treatment groups, the instructors integrated computer simulation tools and an introduction to scientific modeling criteria in the curriculum. This modeling curriculum replaced the original traditional curriculum that had only asked students to observe magnetic phenomena and remember scientific models of magnetism and scientific laws of magnetism. In the middle school and high school comparison groups, the instructors taught students about magnetism using the original, traditional school curriculum. The treatment and comparison groups in the middle school were taught by the same teacher, and the treatment and comparison groups in the high school were taught by the same teacher as well.

For the modeling curriculum, the role of the instructors was to guide students' observation of magnetic phenomena and introduce the computer simulation tools in the activities, as well as facilitate the students' reflection on the scientific modeling criteria. The scientific models of magnetism were not delivered by the instructors to the students.

*Modeling Curriculum*

In this modeling curriculum, the students engaged in model-based inquiry in which they were guided to self-develop, evaluate, and modify their explanatory models of magnetic phenomena. This model-based inquiry is perceived as similar to how experts solve an unfamiliar problem by employing repeated model construction cycles (Clement, 2008c; Rea-Ramirez, Clement, & Nunez-Oviedo, 2008). Six main inquiry activities in the curriculum were designed based on the goal of teaching student-centered and model-based inquiry. This curriculum was modified based on our previous curriculum for college students with a non-science major (Cheng et al., 2014). Due to the students' difficulty with the open-ended inquiry, we modified the original open-ended inquiry activity to a semi-open-ended inquiry activity. Teachers employed the first three activities in the first class on learning about magnetism; they employed the fourth activity in the second class, and the fifth and sixth activities in the third class.

*The first class: Activate reasoning at the microscopic level.* In the first activity, students observed the interaction between two magnets. In the second activity, students used their observation of the interaction between the two magnets to predict and explain what would happen when the magnet was cut into pieces. The students were asked to examine whether they should revise the models to explain their observation. The third activity involved an interactive computer simulation that prompted students to develop and examine their models at the microscopic level and then select the models that best explain the observations. The simulation tool can be accessed on our website (http://blog.ncue.edu.tw/mcheng2/doc/35148).

*The second class: Introduction to the epistemology of the scientific model and modeling.* The fourth activity included a black box as a scientific phenomenon. The students had to guess what might be inside the box through their observation of the outside of the box. This activity introduced the nature of models as a representation of the students thought what might be inside the box, instead of the appearance of the box. Next, the instructors introduced scientific modeling criteria by comparing solid and hollow earth models and then used this comparison to elicit students' ideas about scientific models and model evaluation criteria. Following this, the instructors introduced the nature of the scientific model, modeling, and scientific modeling criteria to the students. At the end of the class, students were required to use these criteria to evaluate and then revise their own models of magnetism.

*The third class: Model-based inquiry with scientific modeling criteria.* The fifth activity was a semi-open-ended inquiry activity. The students had to use their models to predict and explain the arrangement of iron wires in a box and the direction of the compass needle before and after a bar magnet was attached to the box. Then, the students were asked to use scientific modeling criteria to reflect on the models. In the sixth activity, the students continued the open-ended inquiry. They used materials such as disc magnets and several small bar magnets by designing inquiry activities that examined the models. The students reflected on the scientific modeling criteria and then revised the models.

*Reflection on Scientific Modeling Criteria*

The current research revised some of the previously used criteria (Cheng et al., 2014) based on the students' confusion about the use of the scientific criterion of consistency and the definition of models. After examining the processes scientists use to construct models (Clement, 1989, 1994; 2003, 2008c; Nersessian, 1999, 2008) and students use to construct models (Cheng & Brown, 2010; Clement, 2008a; Rea-Ramirez et al., 2008; Williams & Clement, 2006), we proposed four criteria—explanatory and predictive power, as well as internal and external consistency—as the scientific modeling criteria for the students to use when they discussed, evaluated, and refined their models. The students were also asked to examine their self-developed models based on the definition of models in this research. We prompted students to construct coherent and sophisticated explanatory models similar to the "domain model" or the "atomic magnets model." The reflective questions the students were required to use to examine their constructed model are listed in Table 1.

**Table 1. Reflective questions to facilitate model construction and revision.**

| Criteria for reflection on explanatory models | Reflective questions |
|---|---|
| Definition of model | Can this model explain the hidden and non-observable mechanisms and the cause and effect underlying the observed phenomenon? |
| Predictive power | Can this model more accurately predict the phenomena? |
| Explanatory power | Can this model better explain all findings? |
| Internal and external consistency | Do the components of this model logically connect without contradiction? Is this model consistent with what you already know or experience and with your assumption about how the world works? |

*Data Collection*

Before and after the curriculum was delivered, the students in the treatment and comparison groups completed a survey about the Understanding of Models in Science (SUMS; Gobert et al., 2011; Treagust et al., 2002), explanations of magnetism, and justifications for the criteria the students employed to evaluate their explanations. The assessment of the curriculum relied on quantitative and qualitative measures of these three dimensional outcomes, in the form of pre- and post-surveys.

*Assessing students' views of the nature of the models.* The SUMS survey (Treagust et al., 2002) was adopted to investigate the change in the students' understanding of the nature of models and modeling before and after the curriculum was delivered. The SUMS is a five-point Likert scale assessment that evaluates students' model understanding in five aspects: "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). The reliability for the SUMS ranged from 0.71 to 0.84 in Treagust et al.'s study.

*Assessing students' explanatory models of magnetism*. In the pre-test and the post-test, the students wrote explanations for three magnetic phenomena: why the ends of the magnet attracted the iron nails, why originally the iron nails did not attract other iron nails, and why the iron nails attracted other iron nails after they were stuck to the magnet.

The students' responses were coded according to five levels of explanations established by previous researchers (Cheng & Brown, 2015; Cheng & Lin, 2015; Cheng et al., 2014) to examine whether the students developed models to illustrate the underlying microscopic mechanism and coherently explain the observed phenomena. For Levels 1 to 3, the students' explanations were classified according to whether they described observable events, visualized unknown material, or visualized microscopic elements. For Levels 3 to 5, the students' explanations were classified based on whether they employed their microscopic models to explain one phenomenon, two phenomena, or all three magnetic phenomena.

*Assessing modeling criteria.* The students were asked to record the criteria they used to evaluate their models before and after the curriculum was delivered. In the pre- and post-tests, the students were asked about the model evaluation criteria used to assess whether a model was a good scientific model.

The model evaluations were coded according to the levels of the students' epistemic criteria, proposed by

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Pluta, Chinn, and Duncan (2011). The students' proposed modeling criteria were classified into five levels. For Levels 1 to 3, the students' modeling criteria classifications were based on whether the students proposed vague criteria or misconceptions about scientific modeling, communicative aspects of modeling criteria that convey the meaning of model, or primary criteria that are central to the practices of science. For Levels 3 to 5, the students' modeling criteria were classified based on whether they proposed one, two, or three of the primary criteria. Higher levels of explanation revealed that the students possessed advanced understanding of scientific modeling criteria, which is similar to how scientists evaluate models.

*Data Analysis*

To examine whether there was a difference before and after the curriculum was delivered, of the three dimensions (understanding of the nature of models, sophistication and coherence of the explanations, and proficiency of the model evaluation), the first dimension was assessed according to the rating on a 1–5 Likert scale. The second and third dimensions were categorized into five-level rating scales. An analysis of covariance (ANCOVA) was conducted on the post-test scores with the pre-test scores as the covariates to determine the differences between the treatment and comparison groups.

## Results of the Research

*Comparison of Middle School Treatment Groups and Comparison Groups*

The middle school students' scores on the pre-test and the post-test about their understanding of models in science, explanatory models of magnetism, and modeling criteria were analyzed by comparing the treatment ($n = 59$) and comparison ($n = 92$) groups. ANCOVA was used to equate the pre-test results when determining statistically significant differences in the post-test results.

The results in Table 2 show the statistical analysis of the students' pre-test and post-test scores. This indicates that there were statistically significant differences between the treatment and comparison student groups in the five sub-factors of the students' views of scientific models ($F$MR(1,148) = 10.21, $F$ER(1,148) = 8.16, $F$ET(1,148) = 12.13, $F$USM(1,148) = 17.08, $F$CNM(1,148) = 22.85, $p < 0.05$), explanatory models ($F(1,148) = 57.20$, $p < 0.05$), and modeling criteria ($F(1,148) = 59.26$, $p < 0.05$). The students who participated in the modeling curriculum improved their understanding of scientific models and their ability to develop and evaluate models in comparison to the students who were delivered only scientific models and laws of magnetism.

**Table 2. Descriptive statistics for middle school students' understanding of models in science, and ANCOVA test comparing pre-test and post-test results.**

| SUMS | Research Group | Pre-test | Post-test | *F* |
|---|---|---|---|---|
| | | Mean (SD) | Mean (SD) | |
| MR | Treatment | 4.24 (0.42) | 4.31 (0.65) | 10.21 ($p = 0.02$)* |
| | Comparison | 3.85 (0.63) | 3.81 (0.66) | |
| ER | Treatment | 3.31 (0.62) | 3.08 (0.78) | 8.16 ($p = 0.01$)* |
| | Comparison | 3.31 (0.64) | 3.42 (0.69) | |
| ET | Treatment | 4.16 (0.52) | 4.32 (0.73) | 12.13 ($p = 0.01$)* |
| | Comparison | 3.81 (0.69) | 3.78 (0.66) | |
| USM | Treatment | 4.26 (0.66) | 4.46 (0.65) | 17.08 ($p < 0.01$)* |
| | Comparison | 3.83 (0.74) | 3.85 (0.72) | |
| CNM | Treatment | 4.32 (0.67) | 4.57 (0.60) | 22.85 ($p < 0.01$)* |
| | Comparison | 3.93 (0.76) | 3.90 (0.76) | |

| Explanatory models and modeling criteria | Research Group | Pre-test | Post-test | F |
|---|---|---|---|---|
| | | Mean(SD) | Mean(SD) | |
| Explanatory models | Treatment | 1.59 (1.161) | 2.46 (1.63) | 57.20 ($p < 0.01$)* |
| | Comparison | 1.09 (0.38) | 1.00 (0.00) | |
| Modeling criteria | Treatment | 3.00 (0.97) | 4.03 (1.16) | 59.26 ($p < 0.01$)* |
| | Comparison | 2.08 (1.17) | (1.25) | |

* $p < .05$

*Comparison of High School Treatment Groups and Comparison Groups*

To determine statistically significant differences between the treatment ($n$ = 40) and comparison ($n$ = 33) groups of high school students, ANCOVA was utilized on the students' post-test scores of their understanding of models in science, explanatory models of magnetism, and modeling criteria with their pre-test scores as covariates. This approach controlled for any differences in the pre-test scores for the treatment and comparison groups.

The ANCOVA results, shown in Table 3, indicate that the high school students in the treatment group had a statistically significantly better understanding of models in science in terms of MR, ET, and USM ($F$MR(1,69) = 4.04, $F$ET(1,69) = 18.00, $F$USM(1,69) = 11.09, $p < 0.05$). However, no statistically significant differences were found in the sub-factors ER and CNM ($F$ER(1,69) = 0.21, $F$CNM(1,69) = 1.54, $p > 0.05$) compared to the students' comparison group peers. Students in the treatment group also achieved statistically significantly better post-test scores in developing explanatory models ($F(1,69) = 11.02$, $p < 0.05$) and modeling criteria ($F(1,69) = 29.38$, $p < 0.05$). This means that the high school students who participated in the modeling curriculum improved their understanding of scientific models in only three aspects (MR, ET, and USM), as well as their ability to develop and evaluate models, in comparison to the students who were delivered only scientific models and laws of magnetism.

**Table 3. Descriptive statistics for high school students' understanding of models in science, and ANCOVA test comparing pre-test and post-test results.**

| SUMS | Research Group | Pre-test | Post-test | F |
|---|---|---|---|---|
| | | Mean (SD) | Mean (SD) | |
| MR | Treatment | 4.17 (0.40) | 4.45 (0.39) | 4.04 ($p$ = 0.04)* |
| | Comparison | 4.02 (0.35) | 4.21 (0.36) | |
| ER | Treatment | 3.09 (0.63) | 3.09 (0.63) | 0.21 ($p$ = 0.89) |
| | Comparison | 3.11 (0.50) | 3.12 (0.56) | |
| ET | Treatment | 4.13 (0.41) | 4.53 (0.55) | 18.00 ($p < 0.01$)* |
| | Comparison | 4.13 (0.43) | 4.06 (0.45) | |
| USM | Treatment | 4.20 (0.69) | 4.70 (0.43) | 11.09 ($p < 0.01$)* |
| | Comparison | 4.12 (0.49) | 4.31 (0.55) | |
| CNM | Treatment | 4.50 (0.55) | 4.68 (0.46) | 1.54 ($p$ = 0.22) |
| | Comparison | 4.09 (0.72) | 4.37 (0.70) | |

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| Explanatory models and modeling criteria | Research Group | Pre-test | Post-test | F |
|---|---|---|---|---|
| | | Mean(SD) | Mean(SD) | |
| Explanatory models | Treatment | 3.15 (1.44) | 4.00 (1.40) | 11.02 ($p$ < 0.01)* |
| | Comparison | 2.67 (1.53) | 2.79 (1.43) | |
| Modeling criteria | Treatment | 3.35 (1.21) | 4.40 (0.98) | 29.38 ($p$ < 0.01)* |
| | Comparison | 3.12 (1.27) | 3.09 (1.28) | |

* $p < .05$

## Discussion

It has been suggested that constructing models is more productive than using models in learning, because solving or answering conceptual questions requires learners to construct models as a foundation for prediction, inference, reasoning, and experimentation. Moreover, when students construct their own models, the students have ownership of the knowledge, which is vital for making sense of abstract concepts and constructing knowledge (Jonassen, Strobel, & Gottdenker, 2005). The findings of this research support this argument by revealing that when students were scaffolded to self-develop their own models through the modeling activities, the students developed more sophisticated and coherent models than the students who only received scientific models from their instructors.

Model building has been perceived to assist students to reflect on their modeling processes (Jonassen et al., 2005). When students are asked to generate, evaluate, and modify models to explain scientific phenomena, the students are more likely to self-generate models with more coherence or explanatory mechanisms (Bamberger & Davis, 2011; Maia & Justi, 2009; Schwarz et al., 2009). Nevertheless, research has also indicated that students often reflect on modeling with criteria related to their personal preference, instead of scientific model evaluation criteria (Cheng & Brown, 2015; Pluta et al., 2011). Thus, our previous studies (Cheng & Brown, 2015) suggested a curriculum should be designed that explicitly scaffolds students' reflection on scientific modeling criteria.

Accordingly, a method for scaffolding students' learning of modeling is implemented in the present research and is found effective. In addition to asking students to generate, evaluate, and revise the models, this method involves three essential elements: activities that provide the required concepts for modeling at the microscopic level, introduction to scientific models and modeling, and scaffolding of students' reflection on their models with scientific modeling criteria. In this way, students not only learned how to develop scientific models and how to evaluate and revise their models in a scientific way but also have a better understanding of the nature of models and modeling.

Nevertheless, in this research, the target model in both the treatment and control groups was the domain model of magnetism, a microscopic model in physics. Students in the treatment groups were asked to reflect on the hidden and non-observable mechanism underlying their observed phenomena in this context. Hence, the design of the modeling curriculum could not be applied to other types of models (e.g. macroscopic models). It could be possibly further applied to teach students about scientific models that require microscopic reasoning, such as electricity, light, and gas. More research is required to design the modeling curriculum to help students learn about other science topics.

## Conclusions

This research showed that the modeling curriculum, which engages students in reflective thinking with scientific modeling criteria at the microscopic level, enhanced middle school and high school students' learning performance in terms of their views of scientific models, as well as developing explanatory models of magnetism and modeling criteria, compared with the traditional curriculum. The middle school students seemed to have a better understanding of scientific models than the high school students. Why this curricu-

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lum, which covers microscopic reasoning and learning the views of scientific models, benefits middle school students more than high school students requires further investigation.

Our previous research pointed out the positive relationships between students' understanding of scientific models and their model development, as well as their performance and interest in learning science (Cheng & Lin, 2015). The present research shows that the use of modeling curriculum enhances students' views of scientific models and model development, and may possibly encourage students' performance and interest in learning science in school.

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