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Comparison of Modeling Practice Representations in Science Educational Standards between China and the United States

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Abstract: *Scientific modeling competence has been considered a major component of students' scientific literacy. In China, this perspective has been endorsed by the new standard of high school curriculum, which has influenced the creation of new-generation textbooks and teaching activities. Based on the analytical framework proposed in the recent academic literature, this study accesses the representations of modeling practices in the 2017 High School Science Curriculum Standards (HSSCS) and the Next Generation Science Standards (NGSS), regarding the extent, the distribution of the modeling practice representations (Model Selection, Model Construction, Model Validation, Model Analysis and Model Deployment), the quality (from L1 to L5), and the overall consistency of different aspects. The findings indicate substantial disparities in the representations of modeling practice in HSSCS and NGSS. The aspects of the modeling practice are fully represented by only HSSCS. For the four educational standards documents, the modeling practice representations are distributed unevenly throughout the contents, most of which are presented in Physical Sciences (PS) and Life Sciences (LS). Meanwhile, the requirement of the model verification for students is poorly or inconsistently represented in HSSCS and NGSS. It is recommended that explicit representation and broader dissemination of modeling practice be incorporated into the HSSCS.*

Keywords: *modeling practice; representation; High School Science Curriculum Standards; NGSS*

1. Introduction

In recent years, there has been a global effort to improve students' scientific literacy through a new round of science curriculum reform[1]. Among the various components of scientific literacy, scientific modeling, a kind of complex high-level scientific practice, has attracted special attention[2,3]. A sophisticated understanding of developing and using models is also an essential characteristic of modern citizens with scientific literacy[4], as 'it is essential to their learning of science concepts, methodological processes and the development of an awareness of how science operates'[5,6]. Therefore, promoting students' modeling skills has become a significant objective in science education worldwide[7]. For instance, developing and using models in 2012 was recognized as one of the eight core practices in science education by the new Framework for K-12 Science Education in the U.S.

In the science education community, there is an emerging trend that emphasizes the importance of developing students' abilities to use models to enhance their scientific literacy[8]. Consequently, numerous researchers have advocated for the implementation of model-based teaching and learning, commonly referred to as modeling-based instruction (MBI), in science education. Moreover, these researchers have devoted their efforts to exploring and examining instructional strategies that hold the potential for effectiveness within MBI[9-11]. It has been discovered that Various factors, such as teachers' views of models, instructional methods and strategies, and students' prior beliefs, can influence modeling competence[12-15]. However, the representation of exemplary practices in instructional materials (including curriculum standards), which plays a critical role in guiding teaching and learning, has not received enough attention.

When studying modeling practice, the framework proposed by different researchers has been widely applied to identify the various dimensions[16] and levels of modeling practice in many countries[17]. However, there has been limited research conducted to analyze the representations of modeling practice

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in curriculum standards. Meanwhile, in the most recent revision of curriculum standards in Chinese mainland, the modeling practice has been included explicitly in the 2017 High School Science Curriculum Standards (HSSCS) [18]. Therefore, it is important to investigate the extent to which modeling practice is represented in the current high school curriculum standards in Chinese mainland and the U.S. This investigation can shed light on the extent to which modeling practice is integrated into these educational frameworks. The results can inform science educators regarding the aspects of modeling practice representations in current high school curriculum standards and thinking about how to improve students' modeling practice with curriculum standards.

2. Research questions

Previous studies on modeling competence assessment mainly focus on meta-modeling knowledge and modeling products[19]. In contrast, the assessment of modeling practice has not yet been thoroughly examined, especially in the representations of modeling practices. Modeling practice is at the heart of the scientific endeavor [20-22]. Science educators are increasingly interested in incorporating modeling practice into students' science instruction[23-25]. National educational standards documents are essential teaching materials. Instruction can be organized around a progression of models based on national curriculum standards, which helps students build upon their existing understanding and develop more scientific ideas[26]. The representations of modeling practices, such as models and modeling, are consistently highlighted in educational standards documents from various countries. A consensus has been reached that the modeling practice should be spread across the instructional process, ensuring consistent and gradual exposure for students to enhance their comprehension of various modeling aspects. Nevertheless, educational standards documents may vary in their allocation of emphasis when incorporating modeling practice, depending on the specific content areas[27].

The framework of modeling practice developed by Hestenes[28,29] and Halloun[6,16] provided a meaningful way to analyze the process of modeling practice, including model selection, construction, validation, analysis, and deployment, which has been modified by Liu and Chiu[30]. However, there has been limited research on how modeling practice is represented in educational standards documents.

Science education literature addresses modeling practices, such as modeling activities, model-based learning practices, or modeling phases. In this article, we will use the term "modeling practice" as a broad term encompassing any representations of modeling behavior or cognitive operation while being engaged in modeling, which includes model selection, model construction, model validation, model analysis, and model deployment in educational standards documents. In the present study, the modeling practice representations between HSSCS and NGSS are assessed according to the framework modified by Liu and Chiu, which contains five aspects and five levels of each aspect. Therefore, this study presents valuable perspectives on the representations of modeling practice of developing and using models and allows discussion of differences in educational standards documents. This study was conducted to bridge this gap by examining the modeling practice representations between HSSCS and NGSS with a particular emphasis on two research queries:

- RQ1: How are the five aspects of modeling practice represented in HSSCS and NGSS?
- RQ2: How are the modeling practice representations distributed in each curriculum standard?

3. Methodology

3.1. Materials

In Chinese mainland, students learn science in four separate subjects (biology, chemistry, physics, and geography) during high school period. Commonly, the authorized curriculum documents, which frequently outline educational benchmarks, establish the aims, targets, substance, and evaluation methods of a specific field of study. They mirror the fundamental norms and criteria of a nation or locality, thereby significantly impacting students' learning, teachers' pedagogy, and textbook development, particularly influential in areas of China where public schools are prevalent[31]. Students' performances are typically evaluated based on the curriculum content and teaching objectives outlined in their country's official curriculum documents. Therefore, modeling competence included in the High School Chemistry Curriculum Standards (HSCCS), the High School Biology Curriculum Standards (HSBCS), the High School Physics Curriculum Standards (HSPCS), the High School Geography Curriculum Standards (HSGCS) in 2017, and the NGSS are chosen for analysis.

The complete procedure undertaken in this study is illustrated in Figure 1. The content of both versions of the curriculum standards relating to models and modeling were examined and compared.

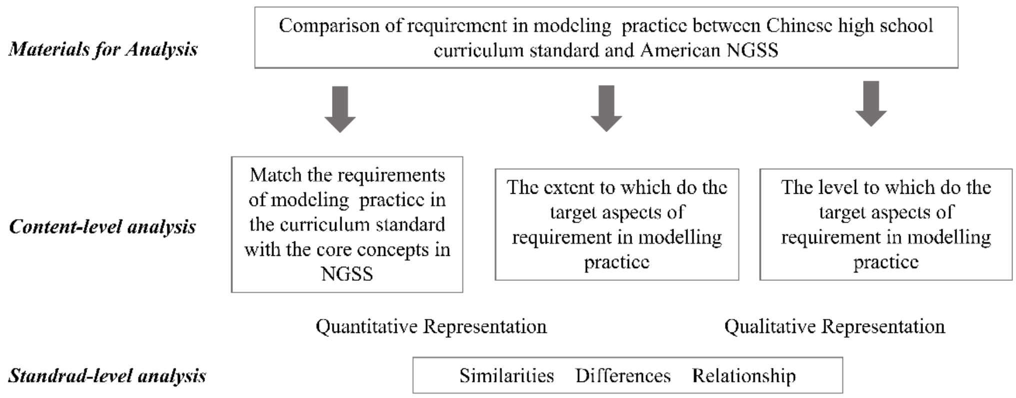

Figure 1. The analysis framework.

3.2. Analytical framework

The chosen materials were analyzed at both the content level and the standard-level. Specifically, at the content-level, the target modeling content in two versions of the curriculum standard, the frequency of five aspects, and the level of modeling practice were analyzed separately. Then, the results were used to guide the research at the standard-level to determine the similarities and differences in the requirements for modeling practice between NGSS and HSSCS and how they correspond to each other. The analytical framework is presented in Figure 1 and will be further explained in the subsequent section.

3.2.1. Five Aspects of Modeling Practice

The five-aspect framework of modeling practice proposed by Chiu et al.'s[32] was adopted in this study. This framework, detailed in Table 1, serves several purposes in our study. Firstly, the five-aspect framework will be used to ensure transparency in our theoretical position. Secondly, the framework will be utilized as a basis for our analysis of these educational standards documents, and the rationale for including models and modeling in their curriculum standards. Finally, the framework will be employed to discuss the disparities and resemblances present in the two iterations of curriculum standards. This discussion will facilitate the fine-tuning of the curriculum standards concerning modeling. It is worth noting that modeling involves multiple processes; the five aspects of modeling practice are interconnected and dependent on each other. To systematically classify the materials. To systematically classify the materials, only the dominant aspect reflected was labeled in the analysis.

Table 1. Revised checklist for analyzing five aspects of modeling practice of two versions of science curriculum standard.

Level	Description	Score
L1 Unstructured	Description of a single related factor	1
L2 Multistructural	Description of the qualitative relationship between two related factors	2
L3 Relational	Reflects on the relationships, interactions, and influences between factors	3
L4 Extended abstract	Reactions that further extend the abstraction of concepts between multiple-factor relationships	4
L5 Scientific explanation	Higher order, complex extended abstractions (explain principles)	5

3.2.2. The Level of Modeling Practice

When relevant contents of the model and modeling are displayed in the curriculum standards, the level of requirements and attainment of objectives stated in the curriculum standards varies. Therefore, the level of modeling is assessed according to the framework of Chiu et al.[32], including L1-L5, which are Unstructured, Multistructural, Relational, Extended abstract, and Scientific explanation (see Table 2).

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Table 2. Revised checklist for the analyzing level of modeling practice of two versions of science curriculum standard.

Level	Description	Score
L1 Unstructured	Description of a single related factor	1
L2 Multistructural	Description of the qualitative relationship between two related factors	2
L3 Relational	Reflects on the relationships, interactions, and influences between factors	3
L4 Extended abstract	Reactions that further extend the abstraction of concepts between multiple-factor relationships	4
L5 Scientific explanation	Higher order, complex extended abstractions (explain principles)	5

3.3. Analysis procedure

The frequency of model content in the two versions of curriculum standards is counted by coding. The steps are as follows:

(1) Browse and analyze all the model content of NGSS and HSSCS for the subsequent analysis.

(2) Mark and code items of the five aspects of modeling practice (i.e., model selection, model construction, model validation, model analysis, model deployment, and model reconstruction) and the level of modeling practice. When the textual materials match a feature representation in the five aspects of modeling practice, the corresponding feature item is recorded as 1-5. Here the score of 1-5 represents the five aspects of modeling practice following the order in Table 1. Then, the selected materials were gathered, in which each piece of material was coded from 1 to 5 according to the level of modeling practice. “1” refers to “Unstructured”, and “5” refers to “Scientific explanation” (see Table 2). The higher the number, the higher the level of modeling practice.

(3) Exam the consistency of each aspect and level of modeling practices throughout each standard. There are two primary researchers and two graduate student research fellows in science education who performed the data analysis independently. By convention, a cut-off of the alpha at .80 is required for a “good” scale. The result shows that the inter-rater reliability indices were also at a moderate level (Cronbach’s Alpha = 0.961 for process, and 0.964 for competence, meanwhile Cohen’s Kappa = 0.883 for process, and 0964 for competence). A discussion of the analytical framework and scoring schema among all researchers resulted in a consensual understanding of the five aspects and the level of modeling practice represented by the selected materials.

4. Results

The results of modeling practice representations in HSSCS and NGSS are summarised in Figure 2, Figure 3, and Table 3. In Figure 2, the proportions of modeling practice representations for various aspects of HSSCS and NGSS are presented. The distributions of the modeling practice aspects across individual chapters within the curriculum standards are displayed in Figure 3. Table 3 lists each modeling practice aspect's individual and total scores for each curriculum standard.

4.1. The quantity and distribution of modeling practice representations between HSSCS and NGSS.

The total quantities of modeling practice representations exhibit notable disparities between HSSCS and NGSS, as indicated by the findings illustrated in Figure 2. The HSSCS contains a more significant number of modeling practice representations, nearly four times as many as the NGSS does (59 vs. 15). Moreover, only the HSSCS has all five aspects represented, while NGSS has missed one——Model Validation. Conversely, it is worth noting that HSSCS exhibits explicit statements that effectively convey the concept of 'Model Validation'. This can be seen in the following two example paragraphs:

Describe the important role of constructing models of thinking in the human understanding of atomic structure and argue the relationship between evidence and model building and its development. (HSCCS, p.39)

Give examples of how human understanding of the structure of matter has evolved and explain the reasons that have contributed to these developments. (HSCCS, p.44)

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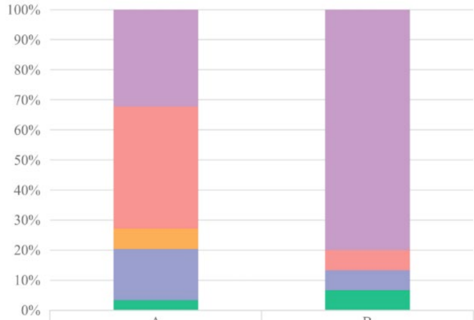
Although the quantities of modeling practice representations for various aspects differ across these curriculum standards, the aspects of Model Analysis and Model Deployment account for more than 70% of the two curriculum standards. Significantly, Model Deployment appears to be the most prominent due to occupying 80% of NGSS.



	A	B
Model Deployment	19	12
Model Analysis	24	1
Model Validation	4	0
Model Construction	10	1
Model Selection	2	1

A: HSSCS; B: NGSS.

The graph displays the relative proportions of modeling practice representations of the five aspects of the curriculum standard. Additionally, the table provides a breakdown of the identified number of representations for each modeling practice aspect within the curriculum standard.

Figure 2. Relative proportions and representation breakdown of modeling practice representations for curriculum standard aspects

Figure 3 illustrates the recorded number and visualization of modeling practice representations within different chapters or content domains, providing a more comprehensive investigation into the distribution of modeling practice within curriculum standards. According to A Framework for K-12 Science Education, science education from K-9 to K-12 could be broadly divided into 11 chapters. The results show that the distribution of modeling practice representations between HSSCS with NGSS in each chapter exists obvious inconsistency. Specifically, only five chapters have modeling practice representations in HSSCS and NGSS, including the Matter and Its Interactions (PS1), Energy (PS3), From Molecules to Organisms: Structures and Processes (LS1), Ecosystems: Interactions, Energy, Dynamics (LS2), and Earth's Systems (ESS2). What is noteworthy is that the distribution of the modeling practice representations is more disparate in the Chinese high school curriculum standards, while it is more balanced in NGSS, particularly in the Matter and Its Interactions (PS1).

PS1: Matter and Its Interactions; PS2: Motion and Stability: Forces and Interactions; PS3: Energy; PS4: Waves and Their Applications in Technologies for Information Transfer; LS1: From Molecules to Organisms: Structures and Processes; LS2: Ecosystems: Interactions, Energy, and Dynamics; LS3: Heredity: Inheritance and Variation of Traits; LS4: Biological Evolution: Unity and Diversity; ESS1: Earth's Place in the Universe; ESS2: Earth's Systems; ESS3: Earth and Human Activity.

Figure 3. The distribution of modeling practice representation in HSSCS and NGSS, which are labeled as A and B.

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4.2. The quality of modeling practice representations between HSSCS and NGSS.

The total scores and average scores of each modeling practice aspect for each curriculum standard are listed in Table 3. The total scores of the two curriculum standards appear to differ significantly due to the number of modeling practice representations, with HSSCS receiving the higher score of 227 and NGSS having the lower score of 62. Therefore, the average scores are used in this study. The results show that even though the total score of modeling practice in HSSCS is nearly four times higher than that in NGSS (227/62), the average score in NGSS is slightly higher than that in HSSCS (4.13/3.84). In addition, the average scores of individual modeling practice aspects suggest that the five aspects were represented in each curriculum standard at level 3 (Relational) and above (Extended abstract) except model validation in NGSS. For example, in HSSCS, two out of five aspects outstripped an average score of 4, including the aspects of Model Construction and Model Validation. These findings suggest that t the chosen materials from the curriculum standards provide valuable insights into the discernible levels of modeling practice aspects.

Since all five aspects reached at least a score of 3 in both of the curriculum standards, the results suggest that five aspects represented the high level of demand for student modeling competencies across different content. Moreover, some aspects reached a score of 5 in curriculum standards, including four of the five aspects in HSSCS and one of the five aspects in NGSS. For example, the following excerpt from the curriculum standards demonstrates how the aspect of 'Model Deployment' was represented in Ecosystems: Interactions, Energy, Dynamics (LS2) reach level 5 of 'Scientific explanation'.

Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. (NGSS, HS-LS2-5)

Use diagrams and other means to characterize and illustrate the processes and features of material cycling, energy flow, and information transfer in ecosystems and to make sound analyses and judgments about relevant practical applications of ecology. (HSBCS, p.26)

The mentioned excerpt from the curriculum standards clearly states the performance expectations that students should try their best to understand correct scientific explanations with the help of different types of models. As a result, these were given a score of 5 (Scientific explanation) in the aspect of modeling practice representations.

Moreover, most of the five aspects received a rating of 4 (Extended abstract) for their representations in curriculum standards. For instance, the aspect of 'Model Deployment' was implicitly conveyed within the curriculum standards. Quoted below are excerpts from the Matter and Its Interactions (PS1), illustrating the aspect of 'Model Deployment' at level 4 of 'Extended abstract':

Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. (NGSS, HS-PS1-4)

Explain the periodic law of the elements (table) about relevant information for the synthesis of new substances and the manufacture of new materials. (HSCCS, p.21)

The above excerpt from the curriculum standards implies performance expectations for students that they should be able to describe mathematical relationships between three related factors at least. As a result, these were identified as representing the aspect of 'Model Deployment' at level 4 of 'Extended abstract' (a score of 4).

Table 3. Scores on different aspects of modeling practice representation.

Aspects of modeling practice		Modeling Practice Scores of Curriculum Standard			
		A	A'	B	B'
1	Model Selection	7	3.5	4	4
2	Model Construction	42	4.2	4	4
3	Model Validation	17	4.25	0	0
4	Model Analysis	89	3.71	3	3
5	Model Deployment	72	3.79	51	4.25
Total		227	3.85	62	4.13

A: HSSCS; B: NGSS.
A': Mean scores of A; B': Mean scores of B.

5. Discussion and conclusions

This research examines the way modeling practice is represented in HSSCS in Chinese mainland and NGSS in the US. The findings indicate that the modeling practice representations in these educational standards documents are inadequate. The quantities of modeling practice represented differ significantly between HSSCS and NGSS. This may result from the Chinese HSSCS, which consists of HSCCS, HSBCS, HSPCS, and HSGCS.

Moreover, HSSCS represented all five aspects of modeling practice, while NGSS missed one——Model Validation. The representation of Model Validation is anticipated to receive limited emphasis in both HSSCS and NGSS. Despite HSSCS containing a substantial number of representations for Model Validation, the focus is predominantly centered on the content of Matter and Its Interactions within HSCCS. Therefore, it is evident that, although Model Validation has been listed as one central process of modeling practice in science education[33], the science education standards in many countries have failed to represent it adequately.

5.1. Distribution of content representing modeling practice

This study has revealed that the content of educational standards documents that pertain to modeling practice is primarily focused on the Physical Sciences (PS) and Life Sciences (LS) in both the HSSCS and NGSS. These educational standards documents are the important ones that list the performance expectations of what high school students should be. The PS in HSSCS and NGSS introduces the general development of physics, which includes Matter and Its Interactions and Energy. Meanwhile, the LS in HSSCS and NGSS mainly have From Molecules to Organisms: Structures and Processes and Ecosystems: Interactions, Energy, Dynamics. However, the Earth and Space Science (ESS) in HSSCS has minimal representations of modeling practice. Compared to the distribution of model practice across NGSS, it is somewhat unevenly distributed in HSSCS. In Chinese science education, the learning requirements of Earth Science are mainly presented in HSGCS. An important reason for the uneven distribution may be that modeling competence has not received enough attention in HSGCS, as opposed to it being mentioned as an explicit learning objective of key competencies in three other standards documents.

Meanwhile, developing a comprehensive understanding of models and enhancing the scientific modeling competence of a student requires consistent exposure to modeling practice. The inclusion of the modeling practice in the science education standards documents allows educators to evaluate the significance of this science practice and how it can be effectively utilized in the classroom[33]. However, this study reveals that the distributions of modeling practice representations in the HSSCS are somewhat unbalanced, where certain aspects of modeling practice are rarely presented in the ESS part. Hence, high school Earth and Space Science teachers may not have given sufficient attention to the importance of modeling practice in their teaching. Furthermore, they may not have access to adequate resources for teaching scientific modeling competence within the instructional materials. Consequently, students enrolled in these ESS courses might encounter limited chances to improve their scientific modeling proficiency.

In addition, it is worth mentioning that in terms of the content level of modeling practice representation, the requirement of model verification for students is relatively consistent in HSSCS and NGSS, which are rarely mentioned. The process of modeling practice goes into five stages: selection, construction, validation, analysis, and deployment[34]. The method of model validation requires students to evaluate the model in different forms of assessment. This practical process could allow students to develop cognitive skills and critical thinking[35].

5.2. Limitations

Due to the restricted focus of this investigation, it is important to acknowledge two limitations when interpreting the findings. First, the scope of this study is limited to representations of modeling practice from grade 10 to grade 12 in HSSCS and NGSS. Therefore, the outcomes cannot be universally applied to other stages in these educational standards documents. In future research, it would be advantageous to analyze the complete educational standards documents, which include kindergarten to grade 12 in science education that may have different content features for requirements of modeling practice.

Second, this study specifically focuses on the educational standards document content only, without making any assumptions about how teachers may incorporate modeling practice into their curricula. Previous studies have proposed that teachers could act as intermediaries between students and

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instructional materials[36]. However, effective implementation of model-based teaching and learning is a challenge for teachers, teacher educators, and curriculum designers[37]. Depending on how teachers utilize instructional materials, they may have diverse and significant impacts on the degree of student engagement with modeling practice. Further research is recommended to explore the dynamics between educational standards documents and their practical application by teachers.

5.3. Implications

Based on this study, it is suggested that the requirements of modeling practice in HSSCS still have significant potential for improvement.

First, the HSSCS should be revised to align with the new curriculum reform requirements and education objectives toward scientific modeling competence. The current version of the HSGCS rarely highlights the importance of fostering students' comprehension of modeling. To ensure consistent development of students' understanding of modeling from kindergarten to grade 12, it is crucial to establish and outline the instructional materials for modeling practice at different grade levels. Further details are described in Appendix H of the Next Generation Science Standards.

Secondly, the developers of these educational standards documents, including both authors and publishers, should cultivate a comprehensive understanding of how to organize effective modeling practice and be committed to explicitly presenting modeling practice requirements in their documents. The representations of modeling practice should be distributed throughout science educational standards documents instead of concentrated in a particular chapter. Nonetheless, it should be acknowledged that not all topics are equally conducive to engaging in modeling practice. The actual distribution of the modeling practice representations needs to be customized based on the features of the subjects' content so that practical modeling practice activities can be appropriately integrated into the curriculum, e.g., in Earth and Space Science. Meanwhile, the requirements of modeling practice should also be adjusted to align with the psychological characteristics and cognitive development patterns of the targeted student population[38].

Finally, both the requirements of modeling practice and modeling-based teaching should aim for a more explicit approach. As discussed previously, modeling practice enables students to consider theory as well as empirical evidence for building explanatory accounts of phenomena. Accordingly, science educational standards documents need to be more explicit in representing all the requirements of modeling practice for students. Moreover, students should also be allowed to reflect on the modeling practice aspects within their learning activities, which will enable them to form a coherent view of modeling. Therefore, in addition to directly analyzing or deploying models, more reflective activities on modeling should be included in the class to guide students to further think critically on the assessment of models, which in turn help students develop modeling competence[39].

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Disclosure statement

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